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BELLINGERITE, A NEW MINERAL FROM CHUQUICAMATA, CHILE

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(Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 225.)

ABSTRACT

Bellingerite. Triclinic pinacoidal. $a:b:c=0.9264:1:1.0149$; $\alpha=105°06'$, $\beta=96°57\frac{1}{2}'$, $\gamma=92°55'$. $a_0=7.22$Å, $b_0=7.82$ Å, $c_0=7.92$Å. Contains $3Cu(IO_3)_2 \cdot 2H_2O$ in unit cell. Habit prismatic [001] and somewhat tabular {100}. Twinning on {$\bar{1}01$} common. Conchoidal fracture. Moderately brittle. H=4. G=4.89±0.01. Color light sulphate green. Optics:

	Orientation		*n*	*Absorption*	*Bx*(+), 2V med.,
	ϕ	ρ	589		$r>v$, strong
X	−70°	70°	1.890	light blue green	
Y	175	38	1.90	light blue green	
Z	34	59	1.99	blue green	

Occurs as distinct crystals in veinlets with leightonite and gypsum in massive quartz at Chuquicamata, Chile.

Named in honor of Mr. H. C. Bellinger, Vice President of the Chile Exploration Company and for many years associated with mining at Chuquicamata.

arly in January of this year the New York office of the Chile Exploration Company, through Mr. H. C. Bellinger, sent to the Harvard Mineralogical Museum some specimens recently found at their mines in Chuquicamata, Chile, for further study in our laboratory. Among these was an iodine mineral, first recognized as probably a new species by the Chuquicamata geological staff and now described in this paper. We are very grateful to the Company, which kindly furnished us with the material for our investigation and an adequate account of its occurrence at the mine.

The mineral is found as tiny, brilliant green crystals of much the same color as the recently described salesite.[1] The crystals are generally less than a millimeter in largest dimension, and often doubly terminated. On some specimens they are perched on blades of leightonite or lying between crystals of that mineral, and on other specimens they are similarly situated on gypsum. The mineral occurs as veinlets not more than a quarter of an inch thick and a few inches long, and as linings in fractures and cracks in an intensely sericitized and silicified granitic rock containing irregular bodies and veins of massive, highly fractured quartz. Earlier fractures in the quartz and granitic rock have been filled with jarosite and minor amounts of iron oxide. The iodine mineral appears to be the latest mineral deposited. It occurs within five meters of the surface at the northwest end of Bench D-1 (Co-or. N4850, E3200).[2]

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[1] Palache and Jarrell, Salesite, a new mineral from Chuquicamata, Chile: *Am. Mineral.*, **24**, 388–392 (1939).

We take great pleasure in naming this new mineral *bellingerite* in honor of Mr. Herman Carl Bellinger, Vice-President of the Chile Exploration Company, who has by his constant interest helped us in the study of Chuquicamata minerals.*

CRYSTALLOGRAPHY

Morphological crystallography. The form distribution as found in the five measured crystals proved beyond a doubt that the mineral is triclinic. The optical and x-ray examinations, as given in another part of this paper, are in agreement with this conclusion. Doubly terminated crystals with the same forms top and bottom indicate that the symmetry class is pinacoidal. The crystals are generally tabular and often elongated in the direction of rather fine striae on the tabular face (Fig. 1).

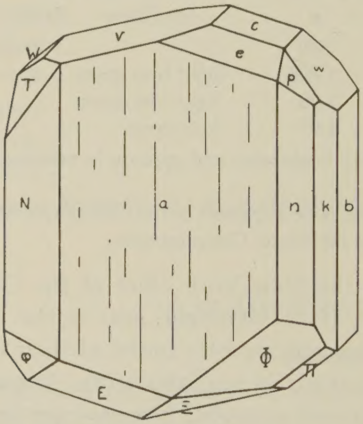

FIG. 1. Bellingerite—Chuquicamata

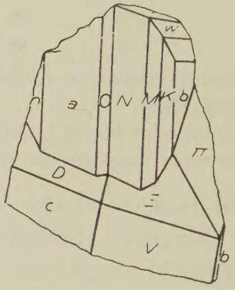

FIG. 2. Bellingerite Twin—Chuquicamata

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[2] We are indebted to Mr. Lester G. Zeihen of the Chuquicamata staff for the foregoing account of the occurrence.

* Mr. Bellinger was General Manager of the Chile Exploration Company at Chuquicamata from 1916 to 1920, and during that time introduced efficient mine methods and mine equipment. From 1920 to date he has been Vice-president in charge of operations for the Chile Exploration Company in New York. Under Mr. Bellinger's direction during this time, complete electrification of the mine, improvement of the bench mining system, and the introduction of liquid oxygen explosives have made Chuquicamata one of the great mines of the world.

Table 1. Bellingerite: Crystallographic Observations

Forms	No. of Faces Observed	Size	Qual.	Measured Range		Weighted Mean		Calculated Values	
				φ	ρ	φ	ρ	φ	ρ
c 001	2	M	A	23°21′– 23°54′	17°05′–17°09′	23°37′	17°07′	23°26′	17°03½′
b 010	5	M	A	0 00 0 10	90°00′	0 00	90 00	0 00	90 00
a 100	6	L	A	85 00 – 85 14	90 00	85 03	90 00	85 03	90 00
k 120	2	M	A	26 38 – 26 40	90 00	26 40	90 00	26 36	90 00
n 210	5	M	A	60 36 – 60 54	90 00	60 37	90 00	60 33	90 00
N $2\bar{1}0$	3	M	B	110 59 –111 14	90 00	111 00	90 00	111 22½	90 00
M $1\bar{1}0$	2	S	C	130 45 –131 18	90 00	130 50	90 00	131 00½	90 00
K $1\bar{2}0$	2	S	B	151 11 –151 48	90 00	151 15	90 00	151 17	90 00
w 011	2	M	A	5 17 – 5 20	53 15 –53 20	5 19	53 18	5 14	53 19
x 021	1	S	C	2°59′	67 20	2 59	67 20	2 56	67 20½
V $0\bar{1}2$	3	L	A	153 03 –154 31	14 33 –15 16	153 13	15 15	153 00½	15 06½
W $0\bar{1}1$	3	S	B	170 56 –171 33	37 38 –37 59	171 01	37 57	171 00	38 04½
X $0\bar{2}1$	2	S	B	176 02 –176 08	61 21	176 03	61 21	176 10	61 23
Y $0\bar{3}1$	1	VS	B	177°26′	70 32	177 26	70 32	177 34	70 53½
d 102	2	S	D	63 37 – 64 38	36 44 –36 50	63 40	36 48	63 58½	36 53
e 101	2	S	C	72 49 – 72 53	52 04 –52 10	72 50	52 09	73 09½	52 01½
D $\bar{1}02$	1	M	B	−61°41′	26 00	− 61 41	26 00	− 61 26½	26 03
E $\bar{1}01$	1	L	D	−78 47	46 50	− 78 47	46 50	− 79 16½	44 57½
p 111	1	M	A	40 31	62 05	40 31	62 05	40 34	62 03½
P $1\bar{1}1$	1	VS	E	119 23	55 38	119 23	55 38	118 56½	54 29
Ξ $\bar{1}\bar{1}2$	3	L	A	−124 22 –124 26	27 29 –27 30	−124 24	27 30	−124 23½	27 29½
Π $\bar{1}\bar{1}1$	3	S	B	131 33 –131 54	52 30 –52 43	−131 34	52 34	−131 32½	52 39½
S $1\bar{2}2$	2	S	B	137 00 –137 16	44 32 –44 45	137 06	44 40	137 06	44 44
σ $\bar{1}22$	1	VS	E	−18 09	53 30	− 18 09	53 30	− 18 25½	53 38½
T $1\bar{2}1$	2	M	A	144 29 –144 35	64 43 –64 51	144 32	64 45	144 43½	64 47
τ $\bar{1}21$	2	M	A	−152 52 –153 03	65 07 –65 10	−152 57	65 09	−152 59	65 09½
φ $\bar{2}11$	1	M	B	−61 20	−67 10	− 61 20	67 10	− 61 13	67 12
Φ $\bar{2}\bar{1}1$	3	L	A	−113 23 –114 59	66 26 –66 33	−114 56	66 28	−114 50	66 28½

The tabular face has been taken as *a*{100} and the direction of the striae on that face as [001]. This orientation is chosen principally because of its suitability for measurement on the two-circle goniometer. The conventional orientation would make the tabular face {001}, and the [001] zone would then consist of a narrow girdle of small, not easily recognizable faces. The axial directions chosen yield a simple form series (Table 2)

TABLE 2. BELLINGERITE: ANGLE TABLE

Triclinic; pinacoidal $-\bar{1}$

$a:b:c=0.9264:1:1.0149$; $\alpha=105°06'$, $\beta=96°57\frac{1}{2}'$, $\gamma=92°55'$
$p_0:q_0:r_0=1.0591:1.0088:1$; $\lambda=74°23\frac{1}{2}'$, $\mu=81°59'$, $\nu=85°03'$
$p_0'=1.1078$, $q_0'=1.0552$; $x_0'=0.1225$, $y_0'=0.2815$

Forms		ϕ	ρ	A	B	C
c	001	23°26′	17°03½′	81°59′	74°23½′	—
b	010	0°00	90 00	85 03	—	74 23½
a	100	85 03	90 00	—	85 03	81 59
k	120	26 36	90 00	58 27	26 36	72 58
n	210	60 33	90 00	24 30	60 33	76 28½
N	$2\bar{1}0$	111 22½	90 00	26 19½	111 22½	89 24
M	$1\bar{1}0$	131 00½	90 00	45 57½	131 00½	95 05
K	$1\bar{2}0$	151 17	90 00	66 14	151 17	100 22
w	011	5 14	53 19	81 51½	37 00½	37 23
x	021	2 56	67 20½	82 44	22 50½	51 33
V	$0\bar{1}2$	153 00½	15 06½	84 23½	103 25½	29 02
W	$0\bar{1}1$	171 00	38 04½	87 30½	127 31½	53 08
X	$0\bar{2}1$	176 10	61 23	90 59	151 09	76 45½
Y	$0\bar{3}1$	177 34	70 53½	92 22½	160 44½	86 21
d	102	63 58½	36 53	55 56½	74 44	26 02½
e	101	73 09½	52 01½	39 31½	76 48	42 27½
D	$\bar{1}02$	− 61 26½	26 03	111 29	77 53	29 30
E	$\bar{1}01$	− 79 16½	44 57½	132 52	82 26½	50 53
p	111	40 34	62 03½	50 55½	47 51	45 55½
P	$1\bar{1}1$	118 56½	54 29	47 29½	113 12	57 50
Ξ	$\bar{1}\bar{1}2$	−124 23½	27 29½	113 42	105 07	42 49½
Π	$\bar{1}\bar{1}1$	−131 32½	52 39½	129 40½	121 49	68 22½
S	$1\bar{2}2$	137 06	44 44	64 21½	121 02	53 24½
σ	$\bar{1}22$	− 18 25½	53 38½	100 49	40 10½	42 02½
T	$1\bar{2}1$	144 43½	64 47	62 49	132 23½	74 22
τ	$\bar{1}\bar{2}1$	−152 59	65 09½	118 43	143 57	82 11½
φ	$\bar{2}11$	− 61 13	67 12	140 03	63 39	66 41½
Φ	$\bar{2}\bar{1}1$	−114 50	66 28½	149 34	112 39	79 35

and coincide with the independently determined axial directions found in the x-ray study.

The crystals are rich in forms, most of which are of excellent reflecting quality. We have not examined many crystals in order to attain a large list of forms, but certainly the most important ones are included in the list given in Table 1. In this table the range of angles, general quality, and number of readings are given for each of the forms on four crystals. The agreement between measured and calculated angles is, in general, very good.

Table 2 is the calculated angle table. The adequacy of the orientation is indicated by the preponderance of forms with unit indices.

X-ray crystallography. One of the crystals used for the morphological study was also used for the x-ray work. Weissenberg pictures about [001] and [100] were taken, and these verified the morphological choice of axial directions and unit form. The absolute dimensions of the axes are:

$$a_0 = 7.22\ \text{Å}, \qquad b_0 = 7.82\ \text{Å}, \qquad c_0 = 7.92\ \text{Å}$$
$$a:b:c = 0.9235:1:1.0128$$

with the axial angles taken from the morphological measurements because those determined from the x-ray photographs are probably not as accurate as the morphological angles. A comparison of the two sets of angles shows that they are in fair agreement:

Morphological—$\alpha = 105°06'$, $\beta = 96°57\frac{1}{2}'$, $\gamma = 92°55'$
X-ray—$\alpha = 104°29'$, $\beta = 97°15'$, $\gamma = 93°11'$

The computed volume of the unit cell (V_0) is 427.78 Å^3, and from this and the measured specific gravity the molecular weight of the unit cell (M_0) is 1267.93.

The x-ray elements, together with the found density, yield a satisfactory chemical formula for the unit, as shown in a later part of this paper.

Twinning. Twins of the new mineral occur on one of the examined specimens. The twinning is on $\{\bar{1}01\}$, producing a combination with a large re-entrant (Fig. 2), or, more often, a thick crystal without re-entrants in which the twinning can most easily be detected under the microscope. The tabular crystals are not twinned. In the Friedel sense the twins have an index of 1, with an obliquity of 3°20′, so that the lattices of both individuals are closely coincident in their twinned positions, and a good geometrical basis for the twin law is established.

PHYSICAL PROPERTIES

The fracture of the mineral is subconchoidal, without any cleavage direction observed. The crystals are moderately brittle; hardness is about 4. The specific gravity, 4.89 ± .01, was measured on six crystal fragments varying from 9.03 to 21.87 mg.

The color is light sulphate green (39′B-G.b of Ridgway); streak very pale green.

Optical properties. A crystal, previously measured on the goniometer, was mounted in arochlor ($n = 1.66\pm$), and used for a study of the optical orientation with the Fedorov stage. Some difficulty was encountered in measuring the positions of the small faces under the microscope because of the large difference in the refractive index between the mounting medium and the mineral. Mounting media of the requisite high index (1.90) have too high a melting point, since the mineral dissociates easily with heat. The position of the indicatrix, as given by the angles below, is accordingly only accurate within a few degrees:

	ϕ	ρ
X	$-70°$	70°
Y	175	38
Z	34	59

On {100}, the flat face, the extinction is essentially parallel to the zone edge $[0\bar{1}1]$ and $X' \wedge [001] = 37°$. The mineral is biaxial positive, with 2V medium, and a strong dispersion, $r > v$. Some absorption in blue-green is noted in thicker crystals with $Z > X$ and Y.

Refractive indices, measured in sodium light, with phosphorus-sulphur-methylene iodide liquids, are:

$$\alpha = 1.890, \qquad \beta = 1.90, \qquad \gamma = 1.99$$

CHEMISTRY

A part of the large sample prepared at the Chuquicamata laboratory was further purified by us and analyzed by Mr. Gonyer. The results are included in the following table:

TABLE 3. ANALYSIS OF BELLINGERITE

	A	B	1	2	3	C
I_2O_5	77.55	78.00	.2337	2.96	78.47	77.59
CuO	18.65	18.76	.2357	2.99	18.70	18.37
H_2O	3.22	3.24	.1798	2.28	2.83	[4.04]
Total	99.42	100.00			100.00	100.0
G	4.89				4.92	4.876

A. Analysis (Harvard 95026). F. A. Gonyer, *analyst.*

B. Corrected to 100 per cent.

1. Molecular proportions of B.

2. Molecular proportions xM_0 (where $M_0 = 1267.93 = V_0 d/A$). The figures in the column are the computed numbers of the oxide in the unit cell.

3. Calculated composition and specific gravity for $3Cu(IO_3)_2 \cdot 2H_2O$.

C. Analysis of artificial crystals by Granger and de Schulten (*Bull. soc. min., France*, **27**, 137–146, 1904).

The analysis yields the formula $3Cu(IO_3)_2 \cdot 2H_2O$, in close agreement with the required molecular weight for the *x*-ray unit, as shown in column 2 of Table 3. The formula originally proposed for the artificial crystals by Granger and de Schulten was $Cu(IO_3)_2 \cdot H_2O$, but this does not fit our data so well as our formula. The analysis (C of Table 3) upon which the old formula rests, gave the water by difference; Mr. Gonyer made a direct determination in his analysis here recorded.

Bellingerite is only slightly soluble in hot water, the crystal edges becoming somewhat rounded on boiling for some time. It is easily soluble in dilute HCl. On heating in the closed tube, it shows the immediate evolution of a heavy purple iodine vapor, which crystallizes on the walls of the tube.

ARTIFICIAL CRYSTALS

Granger and de Schulten prepared triclinic crystals of a supposed cupric iodate monohydrate which conform with our mineral in all respects. The chemical similarity has been shown in the previous section. The crystal orientation by Granger and de Schulten is related to ours as follows:

Granger and de Schulten to Berman and Wolfe

$$00\bar{1}/110/\bar{1}10$$

and conversely, from our setting to theirs is:

$$0\tfrac{1}{2}\tfrac{\bar{1}}{2}/0\tfrac{1}{2}\tfrac{1}{2}/\bar{1}00$$

Their axial ratio is:

$$a':b':c' = 1.2898:1:1.5188$$
$$\alpha' = 82°38', \qquad \beta' = 95°0', \qquad \gamma' = 91°6'^{*}$$

Converted to our orientation this yields:

$$a:b:c = 0.9402:1:1.0205$$

in fairly good agreement with our ratio (Table 2).

We believe our orientation to be more suitable for the discussion of the crystallography of the species, because the forms are somewhat simplified, but principally because our orientation and unit represent the shortest periodicities in the lattice, as verified by the *x*-ray study.

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* In the original paper, the angles were transposed.

The color and specific gravity are also in good agreement with our data and we can safely assume that the natural and artificial material are the same.

RELATION TO OTHER MINERALS

Bellingerite is the fourth iodate recorded as a mineral. Salesite, the recently described basic cupric iodate, $Cu(IO_3)(OH)$, is also from Chuquicamata; and lautarite, the calcium iodate $Ca(IO_3)_2$ is from Atacama, as is dietzeite, the complex iodate and chromate of calcium. The new mineral shows no special relationship to these.

STERRETTITE, A NEW MINERAL FROM FAIRFIELD, UTAH

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AND

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(Contribution from the Department of Mineralogy and Petrography, Harvard University, No. 226.)

ABSTRACT

Sterrettite, $Al_6(PO_4)_4(OH)_6 \cdot 5H_2O$, is found in cavities in pseudowavellite in the variscite deposit near Fairfield, Utah. It occurs in orthorhombic, colorless, simple prismatic crystals. Cleavage: {110} fair, {100} and {001} poor. $H=5$; $G=2.36$. Biaxial neg., $2V=60° \pm 10°$; $r>v$, barely perceptible; $X=a$, $Y=b$; $\alpha=1.572$, $\beta=1.590$, $\gamma=1.601$, all ± 0.003. Elements (morphological): $a:b:c=0.8662:1:0.5325$. Structural lattice: space group $P2_12_12_1$; $a_0=8.90$Å, $b_0=10.20$Å, $c_0=5.43$Å; $a_0:b_0:c_0=0.872:1:0.532$; cell contains $Al_6(PO_4)_4(OH)_6 \cdot 5H_2O$. Named after Dr. Douglas B. Sterrett, one of the first to investigate and describe the Utah and Nevada variscite deposits.

From a large amount of material from the variscite deposit near Fairfield, Utah (Larsen and Shannon, 1930; Larsen, 1940), collected by Messrs. Arthur Montgomery and Edwin Over, a few specimens contain orthorhombic crystals distinct from any previously described mineral. With considerable difficulty sufficient material was purified for a chemical analysis.

The mineral is named *sterrettite* in honor of Dr. Douglas B. Sterrett who was one of the first investigators of the Utah and Nevada variscite deposits.

OCCURRENCE

Sterrettite is colorless and occurs as tiny single crystals, nearly all of which are excellent for goniometric measurement. They are present only in a tan-colored massive pseudowavellite which has tiny irregular pores through it, and in lenticular openings between curving outer shells of the pseudowavellite. The crystals grew with the prism zone normal to the walls of these openings, commonly one crystal to an opening. Knobs and spherules of pseudowavellite projecting into cavities may have several crystals growing from their surfaces in a radial arrangement, but each crystal is separate and perfect. Hexagonal prisms of a member of the apatite group occur in some cavities in the pseudowavellite, but their relation to sterrettite is not shown.

MORPHOLOGY

Sterrettite is orthorhombic and prismatic in habit. The crystals are slightly elongated in the [100] zone, which is the prismatic zone of Fig. 1, and range in maximum dimension from 0.25 to 1.0 millimeter. It is the only mineral found in the nodules forming crystals free of vicinal forms and subparallel growths. The setting chosen is that indicated by the x-ray study.

Seven crystals were measured on the goniometer. The measured range of angles and the best average angles of the observed faces are shown in Table 1. Table 2 gives the formal angle table.

TABLE 1. STERRETTITE—RANGE AND WEIGHTED AVERAGE OF OBSERVED ANGLES TOGETHER WITH THE CALCULATED ANGLES

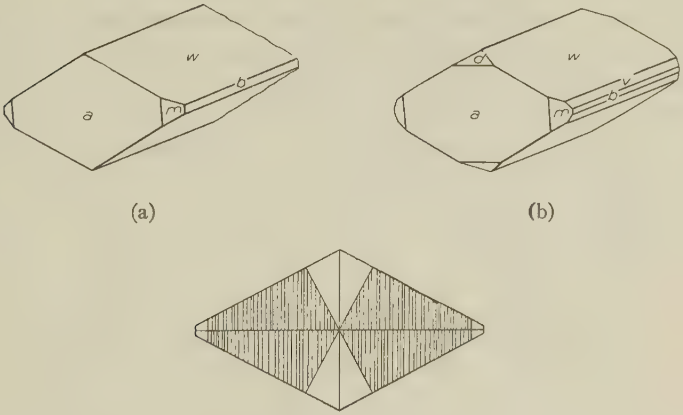
Form	*No. obs.*	*Measured Range*		*Best Average*		*Calculated*	
		ϕ	ρ	ϕ	ρ	ϕ	ρ
b 010	7	—	89°53′–90°48′	0°00′	89°59′	0°00′	90°00′
a 100	7	—	—	90 00	90 00	90 00	90 00
m 110	13	48°54′–49°39′	89 13 –91 38	49 06	89 55	49 06	90 00
w 011	28	—	27 18 –28 47	0 00	28 02	0 00	28 02
v 031	1	—	—	0 00	57 55	0 00	57 57
d 101	3	89 56 –90 00	31 21 –31 38	89 59	31 30	90 00	31 34½

TABLE 2. STERRETTITE—ANGLE TABLE
Orthorhombic Disphenoidal—$P2_12_12_1$
$a:b:c=0.8662:1:0.5325,\ p_0:q_0:r_0=0.6147:0.5325:1$
$q_1:r_1:1=0.8663:1.6268:1$
$r_2:p_2:1=1.8779:1.1545:1$

Form	ϕ	$\rho=C$	ϕ_1	$\rho_1=A$	ϕ_2	$\rho_2=B$
b 010	0°00′	90°00′	90°00′	90°00′	—	0°00′
a 100	90 00	90 00	—	0 00	0°00′	90 00
m 110	49 06	90 00	90 00	40 54	0 00	49 06
w 011	0 00	28 02	28 02	90 00	90 00	61 58
v 031	0 00	57 57	57 57	90 00	90 00	32 03
d 101	90 00	31 34½	0 00	58 25½	58 25½	90 00

The crystals were measured with $a\{100\}$ polar so that the well-developed [100] zone could be used to orient the crystals most accurately. The measured range of angles and the best average angles given in Table 1 have been recast from the actual measured values in the first inversion to their values in the normal setting; since no general $\{hkl\}$ forms were present, the recasting to the normal setting was merely a matter of interchanging the measured values of ϕ or ρ, or taking their supplements.

The prismatic habit is controlled by $w\{011\}$, which is always the dominant form in the [100] zone and reflects a very perfect signal. The pinacoid $a\{100\}$ is always present as a large face, and is the only other important form. The front pinacoid $a\{100\}$ invariably reflects multiple signals, commonly a central signal surrounded by many less distinct signals, none of which is more than two degrees from the polar position. The front pinacoid is shown in a sketch from typical crystals in Fig. 1 (c). Seen under the binocular this face is diamond-shaped with a distinct suture crossing it parallel to the long diagonal; other sutures are seen parallel to the short diagonal on some crystals, or radiating out from the center roughly normal to the (011) edge; faint striae cross the face perpendicular to the principal suture, or on some crystals at an angle to this. This constant suturing is ordinarily suggestive of twinning.



(a) (b)

(c)

Fig. 1. Crystal drawings of sterrettite: (a) usual habit; (b) less common forms; (c) sketch of striae on $a\{100\}$.

The prism $m\{110\}$ is present on nearly all of the crystals; it is usually small, although it reflects a good signal. On some crystals this face is bisected by a horizontal line, and the face reflects a double signal. The side pinacoid $b\{010\}$ is present on many of the crystals, but is narrow, approaching a line-face on some; it reflects a good but in some cases a weak signal.

The dome $d\{101\}$ is normally absent; when present, it is generally smaller than $m\{110\}$, and reflects a weak but good signal. On one crystal measured it was a large, perfect face. The face $v\{031\}$ was observed once as a small but excellent face.

It is stated above that the suturing of the front pinacoid indicates twinning; the division of the *m*{110} faces likewise suggests twinning. Optically the crystals are completely continuous. Thus, if there is twinning, the twin axis must coincide with any one of the crystallographic axes. The *x*-ray study proves that the three crystallographic axes are polar, so that such twinning is possible. The evidence thus strongly indicates, if not proves, twinning about any one of the crystallographic axes, with {001} as the principal composition plane and perhaps *v*{031} as a subordinate composition plane. All of the crystals seen have apparently been twinned in this way.

Although most of the crystals are attached on the front pinacoid, a few could be seen to be doubly terminated.

Physical and Optical Properties

Sterrettite has a fair cleavage parallel to *m*{110}, and two poor cleavages, parallel to *a*{100} and {001}. It has a hardness of 5 and a specific gravity of 2.36 as determined by suspension in bromoform. It has a vitreous luster and is always colorless and clear.

The mineral is practically insoluble in hot acids. A sample was heated for twenty hours in concentrated HCl and less than two per cent of the mineral went into solution. In the closed tube it fuses readily and gives off water, leaving a dark infusible mass.

Its optical properties are:

$$\begin{array}{l} \quad n \\ \left.\begin{array}{l} X=a=1.572\\ Y=b=1.590\\ Z=c=1.601\end{array}\right\}\pm 0.003 \end{array}$$

Biax. neg., 2V=60°±10°
$r>v$, barely perceptible
Colorless.

Structural Elements

Rotation, and zero and first layer Weissenberg photographs about [100] and rotation and zero layer Weissenberg photographs about [001] were taken. The following unit cell dimensions were derived from them:

$$a_0=8.90\text{Å};\quad b_0=10.20\text{Å};\quad c_0=5.43\text{Å};\quad \text{all } \pm 0.02\text{Å}.$$
$$a_0:b_0:c_0=0.872:1:0.532$$
$$V_0=493 \text{ cu.Å.}\quad M_0=705 \text{ for } d=2.36$$

The following are the only spectral omissions:

For: $(h00)$, h odd;
$(0k0)$, k odd;
$(00l)$, l odd.

This uniquely determines the space group $P2_12_12_1-D_2^4$. This proof of disphenoidal symmetry and the consequent polarity of all the crystallographic axes conforms with the evidence of twinning mentioned in the section on the morphology. The fact that a twinned crystal was used in the *x*-ray study need not, in this case, be considered in the determination of the dimensions of the unit cell and the space group; twinning about a crystallographic axis in an orthorhombic mineral only places the positive (top) end of one twin unit in contact with the negative (bottom) end of the other. Since reflection of *x*-rays from the top of an orthorhombic crystal is identical with reflection from the bottom, a twin of this type will reflect *x*-rays exactly as an individual crystal.

CHEMISTRY

A sample, 99 per cent pure as estimated by microscopic examination, weighing 185 milligrams, was analyzed by Mr. F. A. Gonyer. Water was determined by ignition on the whole sample. The ignited sample was divided into two equal parts, one for the determination of alkalies and the other for the remaining constituents. Since H_2O, Al_2O_3 and P_2O_5 together totaled close to 100 per cent, alkalies were not determined. CaO and MgO were absent. The analysis is given in Table 3, together with the molecular and atomic ratios, and the number of atoms in the unit cell, assuming the specific gravity to be 2.36 and $V_0 = 493$ cu. Å. The unit cell content is expressed by the formula:

TABLE 3. ANALYSIS AND RATIOS OF STERRETTITE

	A	B	1		2	3	4
P_2O_5	40.10	38.69	.282	P	.564	3.98	4
Al_2O_3	39.07	41.67	.383	Al	.766	5.40	6
H_2O	20.36	19.64	1.129	H	2.258	15.92	16
CaO	none			O	3.688	26.05	27
MgO	none						
	99.53	100.00					

A. Analysis of sterrettite by F. A. Gonyer. Sample weighed 185 mg. and was 99% pure.

B. Theoretical composition of $Al_6(PO_4)_4(OH)_6 \cdot 5H_2O$.

1. Molecular proportions calculated from A.
2. Atomic proportions.
3. Number of atoms in unit cell, assuming $V_0 = 493$ cu. Å. and $d = 2.36$.
4. Theoretical number of atoms in unit cell.

$$Al_6(PO_4)_4(OH)_6 \cdot 5H_2O$$

The calculated specific gravity for this composition and the above volume of the unit cell is 2.45, which is in poor agreement with the measured value.

RELATED MINERALS

Chemically sterrettite seems to be related to wavellite; the only difference between sterrettite and wavellite is that the former has less water. Optically they are very different. The axial ratios of sterrettite and metavariscite are comparable, if a and c are interchanged in sterrettite and the orientation of metavariscite is that of Strunz and Sztrokay (1939):

Sterrettite	$c:b:a=0.5325:1:0.8662$,	orthorhombic
Metavariscite	$a:b:c=0.5459:1:0.8944$,	monoclinic (?)

Sterrettite is comparable with variscite if c is doubled and interchanged with a and the orientation of variscite is that of Strunz and Sztrokay (*op. cit.*):

Sterrettite	$2c:b:a=1.0650:1:0.8662$,	orthorhombic
Variscite	$a:b:c=1.0217:1:0.8918$,	orthorhombic

However, an x-ray powder photograph of sterrettite is completely different from those of variscite and metavariscite.* Sterrettite is distinct from all other known hydrous basic aluminum phosphates in its optical and physical properties. It must therefore be a distinct species.

ACKNOWLEDGMENT

The writers are indebted to Professor Charles Palache and Dr. Harry Berman for discussions concerning the probable twinning exhibited by sterrettite.

* The metavariscite used was crystalline material from the type locality, Lucin, Utah.

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PETROGRAPHY OF TWO IOWA LOESS MATERIALS[†]

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INTRODUCTION

The Iowa State Highway Commission has found from experience that certain soils, subsoils, and soil parent materials behave differently in the subgrades of roads. Some are stable as foundations, whereas others cause the road to buckle and drain poorly. The standard highway laboratory tests fail to distinguish between these materials, for their properties from the engineer's standpoint are very similar. The slight differences that do occur have not been considered diagnostic. It was with the purpose of affording some explanation of the difference in behavior of these materials that the following work was undertaken. Recent work in clay mineralogy indicates the possibility of applying knowledge of the clay-mineral constituents to practical problems of this nature (2).

The two samples selected for study were as much alike in physical properties as it was possible to obtain, but different as regards behavior in the subgrade. It was decided to investigate these two samples as completely as possible in order to determine their mineralogical character and any significant difference in their mineralogical composition. Chemical, *x*-ray, optical, and base-exchange studies were made.

TABLE 1.[*] PHYSICAL PROPERTIES OF SAMPLES NOS. 1316 AND 1263

Mechanical Analyses—% Passing Sieve

Sample Number	#4	#8	#10	#40	#60	#100	#270	.005 mm.[**]	.001 mm.[**]
1316	100	100	100	100	100	99.8	99.0	28.3	14.8
1263	100	100	100	99.0	97.0	95.0	94.0	25.5	15.1

	Shrinkage Factors		*Density Test*		*Moisture Content %*		*Material Passing #40*		
	Limit	*Ratio*	*Absolute*	*Standard*	*F.M.E.*	*C.M.E.*	*Lower Liquid Limit*	*Lower Plastic Limit*	*Plasticity Index*
1316	19.5	1.73	2.71	1.55	31.4	37.0	38.7	20.8	17.9
1263	16.9	1.84	2.69	1.66	27.7	26.72	32.2	18.3	13.9

[*] Analyses by Iowa State Highway Commission Laboratory at Ames, Iowa.

[**] Determined by Bouyoucos Method.

[†] Part of a Ph.D. thesis. Complete thesis on file at Iowa State College, Ames, Iowa.

Sample No. 1263, of the material that causes trouble in the subgrade, consists of a composite section from 12 to 15 feet deep taken from Marshall County, Iowa (SE. ¼ NW. ¼ sec. 22, T. 83 N., R. 19 W.). The material is gray loess, slightly mottled with iron oxide. It rests immediately upon Kansan till, the upper portion of which has weathered to gumbotil. The loess is Peorian in age. Sample No. 1316, of somewhat similar properties from the engineer's standpoint and which does not cause trouble in the subgrade, is of a composite section, 5 to 11 feet deep taken from Cass County, Iowa (S. ¼ sec. 20, T. 77 N., R. 37 W.). The material is brown loess, mottled with gray and with occasional iron-stained streaks. This material lies 10½ feet above a chocolate-brown gumbotil. The age of the loess is Peorian and the gumbotil, Kansan.

EXPERIMENTAL PROCEDURE

Fractionation. A fractionation or mechanical analysis of material of this nature is essential mainly for three reasons:

1. To obtain an approximation of the size grade distribution of particles.
2. To separate the active or colloidal fraction from the relatively inert or non-colloidal fraction.
3. To facilitate microscopic study, x-ray analysis, chemical analysis, and base-exchange determinations by attempting to secure separates of relatively pure minerals.

The two samples were fractionated according to Bray, Grim, and Kerr (1), with certain adaptations. Every endeavor was made to treat the two exactly alike. One 1500 gram sample from each location was prepared for fractionation by leaching with dilute 1 N CH_3COOH and dilute 0.1 N HCl and washed with distilled water. The samples were then separated into two parts by sedimentation (one fraction containing all those particles greater than one micron in diameter, called the residue, and one fraction containing all those particles less than one micron, the colloidal fraction). This was effected by dividing the samples in two parts and dispersing each part in a very weak NH_4OH solution (2 cc. of conc. NH_4OH in 1500 cc. of distilled water). Each suspension was shaken manually for five minutes in 2½ liter bottles, allowed to stand for 24 hours and the top eight centimeters then siphoned off. This represented the colloidal fraction and the remaining fraction constituted the residue. The bottles containing the residue were again filled up to the original level with the NH_4OH solution and the process repeated. This was done for a total of 63 times or until the total amount of solids being collected per week in the colloidal suspension was less than 0.3 of one per cent of the original sample weight.

The colloidal separate was then fractionated with a Sharples Supercentrifuge into three fractions: the coarse colloid, particles approximately

1 to 0.1 micron in diameter; the fine colloid, 0.1 to 0.06 microns; and the superfine colloid, all those less than 0.06 microns in diameter. These three colloidal fractions and the residue were air-dried and weighed (Table 2).

Table 2. Resumé of Mechanical Analyses by Sedimentation and Centrifuge

Sample	#1263		#1316	
Original weight	1500 gms.	Per cent	1500 gms.	Per cent
Residue	1071.81	71.45	1176.35	78.43
Coarse colloid	105.08	7.00	113.40	7.56
Fine colloid	37.67	2.51	46.36	3.09
Superfine	104.20	6.94	91.09	6.07
Total colloids	246.95	16.45	250.85	16.72
Total colloids and residue	1318.76	87.90	1427.20	95.15
Lost in leaching and handling	181.24	12.08	72.80	4.85

Chemical analysis. Chemical analyses were made of the original samples before the dispersion treatment, and of each of the four fractionated separates (the residue, the coarse colloid, the fine colloid, and the superfine colloid). Standardized procedures were used throughout (Table 3).

Microscopic study. The determination of optical constants of each of the colloidal fractions affords an additional means of supplementing the other data. In addition, separates of the residue ranging in particle size from one to three microns, three to five microns, five to ten microns, and all those particles greater than ten microns were made and studied microscopically. Due to the fact that the clay minerals are micaceous in habit and tend to orient themselves in aggregates, if allowed to settle slowly out of suspension, it is possible to determine several optical constants (4). Optical constants determined were indices of refraction, sign, and 2V. Well oriented aggregates gave good interference figures and permitted the rather accurate determination of the least (α) and greatest (γ) indices of refraction.

X-ray analysis. X-ray powder diffraction patterns were made of all of the colloidal separates of each of the samples. The *x*-ray laboratory of the University of Illinois was made available to the author by Dr. G. L. Clark of the Department of Chemistry and the work was done under the supervision of Dr. W. F. Bradley of the Illinois State Geological Survey.

The equipment used consisted of a Philips Metalix tube with FeKα radiation and what is commonly known as a circular camera. Exposures

TABLE 3. CHEMICAL DATA*

	1263					1316				
	Bulk	Residue	Coarse	Fine	Super-fine	Bulk	Residue	Coarse	Fine	Super-fine
SiO_2	68.69	81.93	54.12	48.89	49.36	69.92	76.15	54.37	46.66	46.62
Al_2O_3	9.93	8.79	21.31	22.26	20.09	11.88	11.33	18.66	19.22	15.51
Fe_2O_3	2.94	1.93	7.25	8.77	9.80	4.45	3.04	8.95	10.83	10.80
FeO	0.40	trace	trace	trace	trace	0.44	trace	trace	trace	trace
MgO	2.34	0.70	2.47	2.72	2.69	1.40	1.02	2.01	2.55	2.49
CaO	4.17	0.96	1.32	1.91	1.82	1.13	0.74	0.57	0.45	0.46
Na_2O	2.86	2.23	1.77	1.18	1.64	1.33	2.52	1.80	1.71	1.18
K_2O	1.63	1.87	1.87	1.47	0.86	1.88	2.45	2.53	1.75	1.06
TiO_2	0.62	0.67	1.13	0.75	0.41	0.66	0.65	0.97	0.66	0.31
P_2O_5	0.10	0.04	0.14	0.09	0.36	0.21	0.04	0.17	0.17	1.53
CO_2	4.01	—	—	—	—	0.22	—	—	—	—
MnO	0.03	0.01	0.09	0.03	0.02	0.09	0.11	0.17	0.07	0.03
H_2O+	2.40	1.89	8.24	8.44	10.35	2.84	3.12	7.23	8.66	9.14
H_2O-	1.68	—	2.99	6.19	3.91	2.70	—	4.36	5.29	7.99
										3.43**
	101.40	101.02	102.70	102.70	101.31	98.71	101.17	101.79	101.02	100.55
SiO_2/R_2O_3	9.88	13.87	3.54	2.98	3.18	8.08	9.74	3.78	3.24	3.54

* Analyses by Gurney and King of Iowa State College.

** Oil from centrifuge.

varied from six to ten hours. Two of the fractions, the fine colloid of sample 1316, and the superfine colloid of sample 1263 were treated with β-naphthylamine (3) to show the presence of the montmorillonite type of clay mineral when, because of the haze at the significant end of the film, it was impossible to tell whether or not this group was present. The large organic molecules spread the lattice of the montmorillonite and consequently so changed the position of its most characteristic diffraction line as to make it easily recognizable if present. Results were computed and tabulated as *d* values (Table 4).

Table 4. *X*-ray Data*

	1316 C	1316 F	1316 S.F.	1263 C	1263 F	1263 S.F.	*d values* Å	*Mineral*
1	M	?	S			?	13.64	Montmorillonite
2	W	W	W	M	M	M	9.85	Illite
3	W	W		M	W	?	7.25	Kaolinite, Illite
4	W.W.	W	W	W.W.	W	W	4.94	β quartz
5	S	S	S	S	S	S	4.49	Clay**
6	S	W.W.		S	W.W.		4.27	Quartz
7		W		M	W		3.55	Kaolinite, Quartz
8	S.S.	S		S.S.	S		3.32	Illite
9	M			M			3.00	Calcite
10	S	S	S	S	S	S	2.59	Clay**
11	S			M			2.45	Quartz
12	M			M			2.28	Quartz
13	W			W			2.24	Quartz
14	S			S			2.12	Quartz
15	M	W.W.		M	W.W.		1.98	Illite, Quartz
16	S			S			1.81	Quartz
17	W	W	W	W	W	W	1.66	Clay**, Quartz
18	S			S			1.53	Quartz
19	S	S	S	S	S	S	1.49	Clay**
20	S			S			1.37	Quartz

* Observed intensities

S.S. = Very strong
S = Strong
M = Medium
W = Weak
W.W. = Very weak

** Not diagnostic of any particular clay mineral.

Base-exchange determinations. Duplicate samples were prepared of each of the four fractions by powdering the material to allow complete and immediate reaction. Care was taken not to powder so vigorously as to destroy the original particle size. Three gram samples of the residue fraction were used, two grams of the coarse colloid, and one gram each of the fine and the superfine colloids. The samples were centrifuged five times with 1 N $Ca(C_2H_3O_2)_2$, washed five times with 70 per cent alcohol and again centrifuged five times with neutral 1 N $NH_4C_2H_3O_2$. The supernatant liquid from the last treatment was saved and Ca determined volumetrically (Table 5).

TABLE 5. TOTAL BASE-EXCHANGE CAPACITY EXPRESSED AS MILLIEQUIVALENTS PER 100 GRAMS OF COLLOID

	Residue	*Coarse Colloid*	*Fine Colloid*	*Superfine Colloid*
Sample 1263	8.70	48.30	69.22	79.05
Sample 1316	13.20	45.31	65.98	95.24

EXPERIMENTAL RESULTS

Sample No. 1263

Residue. Samples representing different particle sizes were separated from this fraction by sedimentation. The coarsest of these, with particles larger than ten microns, contained 95 per cent angular quartz, a few rock fragments, some limonite and muscovite. The fraction containing particles between five and ten microns in size contained about 75 per cent quartz. The rest was mainly limonite and muscovite. Between three and five microns, the amount of quartz decreased to about 60 per cent and the amount of mica increased. A few fragments of kaolinite were also found in this particle range. The fraction containing particles ranging between one and three microns contained the same amount of quartz and mica as the preceding one, and a slightly greater amount of kaolinite. The small base-exchange capacity of this total residue fraction indicates a high degree of separation by the sedimentation process and consequently a general lack of clay minerals.

Coarse colloid fraction. Optical examination of this fraction revealed aggregates whose indices of refraction ranged from 1.569 to 1.574. No aggregates could be obtained with an orientation sufficiently perfect to yield additional information about the optical properties. The *x*-ray diffraction pattern of this fraction showed moderately strong lines of illite (5), kaolinite, calcite, and strong lines of quartz. There was a decided increase in the base-exchange capacity indicating a concentration of the clay minerals. The analyses suggest that this fraction is composed largely of quartz, kaolinite, illite, and calcite.

Fine colloid fraction. The indices of the aggregates ranged from 1.563 to 1.594. Aggregates of almost perfect orientation and hence showing good interference figures were common. The mineral of the aggregates was biaxial, negative, and 2V was about 5 degrees. Indices of refraction for these aggregates were: $\alpha=1.579$, $\gamma=1.584$. The x-ray diffraction pattern revealed moderately strong lines of illite, and weak lines of kaolinite and quartz. Chemical analysis showed less SiO_2 and more Al_2O_3 than the coarse colloid fraction. This is attributed to a smaller amount of quartz. The combined data show that this fraction is composed of illite with small amounts of kaolinite and quartz.

Superfine colloid fraction. A large number of well oriented aggregates were secured (4) whose indices of refraction ranged from 1.554 to 1.574. The best oriented aggregates were biaxial, negative, and $2V=5$ degrees, $\alpha=1.554$, $\gamma=1.573$. The x-ray diffraction pattern showed moderately strong lines of illite, and questionable lines of kaolinite and montmorillonite. An x-ray diffraction pattern of powder that had been immersed in β-napthylamine gave an identical pattern except for a moderately strong line of montmorillonite so moved in position that it could be identified positively. The silica-sesquioxide ratio at 3.18 and the base-exchange capacity at 79.05 were greater than with the fine colloid fraction. This also suggests the presence of montmorillonite. The complete data indicate that this fraction is composed largely of illite and montmorillonite, and that kaolinite is also probably present.

Sample 1316

Residue. About 75 per cent of the particles of the coarsest residue separate, that consisting of particles greater than ten microns in diameter, were quartz. The others were mainly limonitic material. Small amounts of muscovite and magnetite were also present. The other residue separates, those containing particles from five to ten, three to five, and one to three microns in size respectively, were not significantly different except that they had progressively less quartz and more mica, kaolinite, and limonitic material. The iron content of this sample was also higher than that of sample 1263 (Table 3). The base-exchange capacity was quite small, indicating a fairly good separation of the colloidal and non-colloidal materials. This was also true of the residue fraction of sample 1263.

Coarse colloid fraction. The x-ray diffraction pattern of this fraction showed moderately strong lines of montmorillonite and calcite, strong lines of quartz, and weak lines of illite and kaolinite. Indices of refraction ranged from 1.530 to 1.580. Further optical data could not be obtained because of the imperfect orientation. The evidence, chiefly x-ray, indicates that this fraction is composed essentially of montmorillonite, quartz, and calcite.

Fine colloid fraction. Optical examination showed indices of refraction varying from 1.540 to 1.573 and the following values were obtained from many aggregates having good interference figures; biaxial, negative sign, 2V about 10 degrees, $\alpha=1.542$, $\gamma=1.569$. The powder x-ray diffraction pattern revealed a questionable line of montmorillonite, and weak lines of illite, kaolinite, and quartz. The x-ray pattern secured after treatment of the material with β-naphthylamine revealed the unmistakable presence of montmorillonite. The combined data indicate that this fraction is essentially a mixture of montmorillonite, illite, kaolinite, and quartz.

Superfine colloid fraction. The x-ray diffraction pattern of this fraction showed a strong line of montmorillonite and a weak line of illite. The indices of refraction varied from 1.554 to 1.579. The better oriented aggregates gave biaxial interference figures, negative sign, 2V varying from 10 to 20 degrees, $\alpha=1.559$, $\gamma=1.578$. The base-exchange capacity of this fraction was 95.24 milliequivalents per 100 grams, the highest value obtained, and one that can only be accounted for by a large amount of montmorillonite. The data indicate that this fraction is composed chiefly of montmorillonite with a small amount of illite.

Discussion and Summary

The physical properties of the two materials under study, as determined by the highway laboratory through the use of standardized tests, are so similar that it is impossible to differentiate between them (Table 1). Fractionation of the material by sedimentation and a supercentrifuge into several different size separates also fails to reveal any significant difference in amounts of the several grade sizes (Table 2). Accordingly, it is impossible to forecast the behavior of these materials by a comparison of their colloidal content, although it is known that in some circumstances, variations in the amount of colloidal material can be regarded as being diagnostic.

The analytical results show that the samples differ in the nature of their clay mineral content, 1316 being made up essentially of montmorillonite, whereas sample 1263 contains illite and kaolinite as its principal clay mineral constituents. The differences in the characteristic behavior of these clay minerals, montmorillonite, illite, and kaolinite would lead one to suspect that the material containing montmorillonite in larger amounts would behave poorly in the subgrades of roads. However, in this situation the reverse is true and the montmorillonite-bearing material forms the better subgrade. Another condition must be taken into consideration. Sample 1263 was taken from a horizon immediately above a relatively impervious gumbotil, while sample 1316 was taken from material $10\frac{1}{2}$ feet above a similar gumbotil. This relatively impervious layer creates a temporary, perched water table, which in the former case can be expected to interfere with the drainage of the material immediately beneath the slab. In the case of sample 1316 the drainage of the material immediately beneath the slab is not influenced by the gumbotil. Because of this difference in the effect of the gumbotils upon the drainage of the two materials, any variation in the behavior of the materials due to a difference in clay mineral content is felt to be obscured.

A considerable difference in the clay mineral content of these two subgrade materials has been shown, and it is concluded that highway engineers should take into consideration the possibility of differences of behavior being due to such mineral differences, particularly in the colloid fractions, and the geological positions of the materials they plan to use in the subgrades of roads. Differences in the nature of the clay mineral content of materials can be expected to affect their behavior in the subgrade and these differences are apparently not indicated by the standard laboratory tests. The plasticity tests (Table 1) are slightly higher for the montmorillonite material, as would be expected, and a study of more materials will perhaps reveal that this difference should be considered significant.

The great difference in the base-exchange capacity between the colloidal and the non-colloidal fractions of both samples is striking (Table 5). The possibility of using this as a criterion of the perfection of separation between the colloidal and the non-colloidal fractions is suggested.

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FLOW STRUCTURE IN THE LUBBOCK METEORITE, LUBBOCK, TEXAS

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Abstract

The Lubbock meteorite, an aerolite, found near Lubbock, Texas, is unusual in that its internal structure shows the effects of flowage and brecciation. These effects are indicated by the alignment of metallic and non-metallic mineral particles along flowage lines, by an intricate network of small veinlets of nickel-iron and pyrrhotite, and by veinlets of nickel-iron in a "horse-tail" arrangement.

The meteorite described in this paper was found at a point located approximately at Latitude 33°55′ North, Longitude 101°51′ West, which is about one mile south of the city limits of Lubbock, Texas. It is of the aerolite variety, with external features similar to those of other aerolites. However, to my knowledge, its interior structure differs noticeably from that of other aerolites because the arrangement and distribution of the mineral constituents indicates that flowage and brecciation occurred in the stone previous to the time of its flight. The fall was first reported to Mr. H. H. Nininger of the American Meteorite Laboratory by Clifton Morris of the Texas Technological College at Lubbock, Texas, in January 1939, and was subsequently submitted to the writer for detailed examination and description.

Mr. Nininger's general description of the meteorite follows:

> As received at the laboratory, the specimen weighed 1457.8 grams and appeared very unattractive. Only a small part of the surface showed any definite traces of the pitting which is such a prominent feature of certain meteorities. The fusion crust was deeply stained to a distinctly reddish-brown color. In many places this was entirely concealed by a thin coating of oxides. On one side, the specimen showed evidence of having been separated from a larger mass, either late in its flight or after reaching the soil. Long exposure made it impossible to determine which was the case. In spite of its exposure to the weather, the surface of the specimen showed no sign of exfoliation or of fracture.
>
> As to form, the stone was very irregular, about twice as long as it was thick, with one end larger than the other. In cross section it was roughly four sided. There was no indication of an oriented flight. Three small deep elongated pits near the smaller end lay closely parallel. These indicated a direction of air currents at an angle of about 30 degrees with the longitudinal axis of the stone. Two more or less circular pits on the large end were not aligned with such a course.

After photographing, the stone was sectioned near the large end at right angles to the longitudinal axis. Three cuts were made and two slices, approximately 5 mm. and 6 mm. thick, respectively, were removed. One of these slices (Fig. 1A) was polished and used for detailed examination. An additional cut was made to obtain a small fragment suitable in size for the preparation of thin sections.

MINERAL COMPOSITION

The Lubbock, Texas, meteorite contains olivine, enstatite, anorthite, hematite, nickel-iron and pyrrhotite. Of the non-metallic minerals, olivine is the most abundant. Some olivine grains are intimately intergrown with enstatite and the metallic minerals, whereas the majority of them are disseminated throughout an extremely fine-grained and nearly glassy matrix. This matrix probably has a composition approaching the average composition of the contained non-metallic minerals. The majority of the grains range in size from 0.032 mm. to 0.32 mm., but a few of the chondrule type attain a diameter of 1.6 mm. In the latter, the olivine particles are angular in outline and are intimately intergrown with a small amount of enstatite (Fig. 2C).

Enstatite is second in abundance. In addition to constituting a minor part of the olivine chondrules, it occurs rather evenly distributed throughout the mass of the meteorite. Virtually all of the enstatite grains exhibit a fibrous structure. The grains are mostly angular and vary in diameter between 0.16 mm. and 0.64 mm. Only one well developed chondrule of enstatite was observed in the two thin sections examined. This chondrule, also with fibrous structure, is 1.92 mm. in diameter (Fig. 2A). A number of the enstatite grains exhibit fracturing as evidenced by offsetting of the fibers.

Plagioclase feldspar (anorthite) is present but the grains are extremely small and few in number.

Another mineral, reddish-brown in color, which has been assumed to be hematite, occurs as fracture and cavity fillings. In many respects it appears to be of secondary origin. On the walls of small voids, the reddish-brown mineral exhibits a fine concentrically-layered structure, but in the narrow fractures traversing the meteorite the layered structure of the mineral is not evident.

The metallic minerals, nickel-iron and pyrrhotite, also occur in considerable abundance in the stone, but these will be described under "Internal Structure," because of their peculiar arrangement and distribution.

INTERNAL STRUCTURE

The polished surface of the Lubbock meteorite presents a structure which is unique, as far as I am aware, among aerolites. It is rather definitely divided into three zones in which the distribution of the nickel-iron and pyrrhotite indicates both definite flow structure and brecciation. These features are illustrated in the accompanying photograph (Fig. 1A), and in the diagrammatic sketch (Fig. 1B).

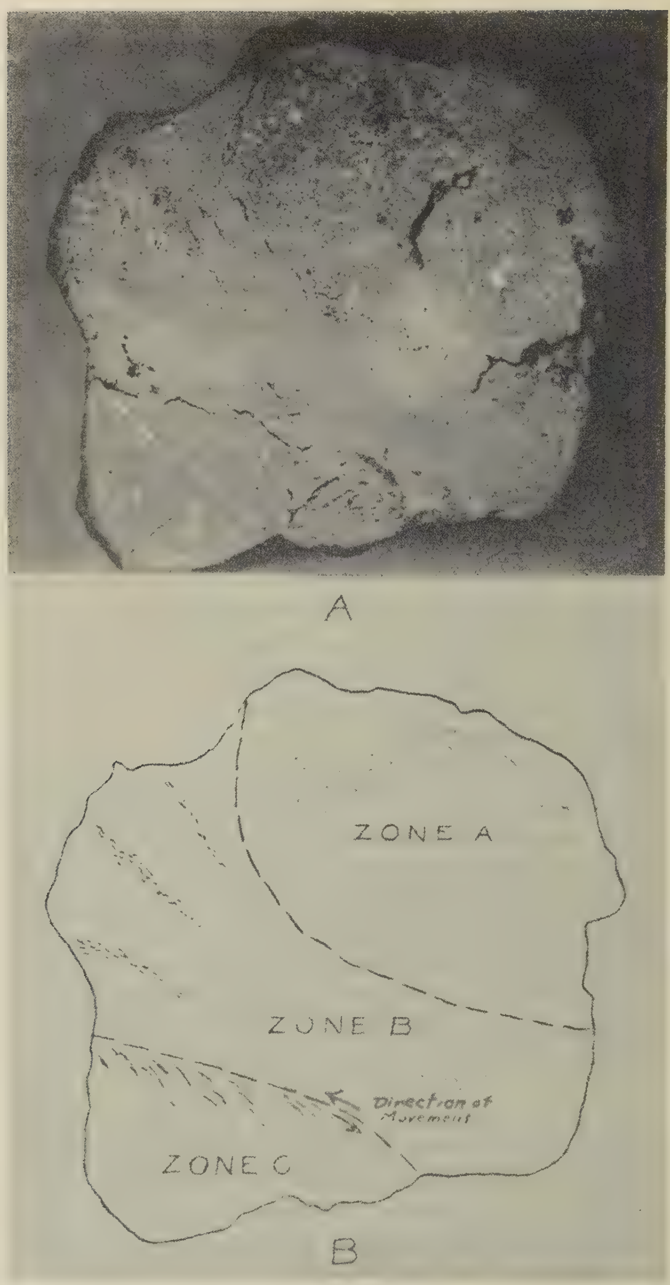

FIG. 1. A. Section of Lubbock meteorite, natural size. B. Diagrammatic sketch of section illustrated in A, showing zones described in article.

Zone *A*, with characteristics typical of many stony meteorites, appears to have been subjected to less disturbance than zones *B* and *C*. Within zone *A* are several chondrules only one of which is evident in Fig. 1A. Nickel-iron and pyrrhotite are rather evenly distributed in this zone. Most of the nickel-iron particles range from 0.2 mm. to 0.4 mm. in diameter, but some have a maximum diameter of 1.6 mm. In contrast, the pyrrhotite particles are mostly smaller than 0.2 mm. in diameter. Nickel-iron and pyrrhotite, in addition to being rather evenly distributed as individual particles, are also closely associated in minute veinlets which form an intricate network throughout zone *A*. The longer and most evident veinlets roughly parallel the contact between zone *A* and zone *B*, but at approximately right angles to these are numerous smaller veinlets. Some of the veinlets traverse the chondrules of enstatite and

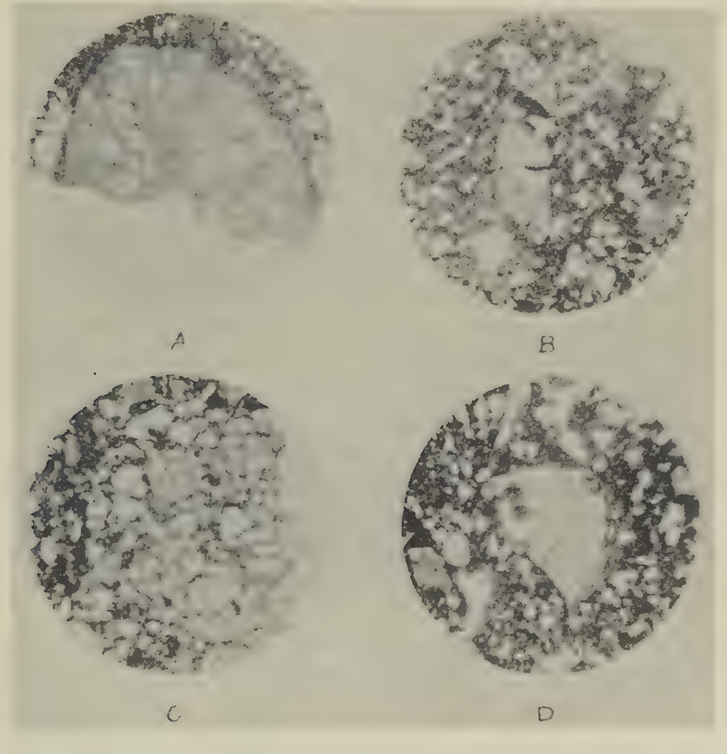

FIG. 2. A. Enstatite chondrule. ×40. B. Broken enstatite chondrule; slight evidence of flowage in right half of illustration. ×40. C. Olivine—enstatite chondrule; alignment of grains indicating flowage near left edge of illustration. ×40. D. Olivine crystal. ×40.

olivine. Another characteristic of zone *A* is the slight but apparent increase in pyrrhotite along the outer edge of the meteorite and also near the contact between zone *A* and zone *B*. Hematite in veinlets and in isolated areas is relatively prominent in zone *A*. Its greatest concentration is near the edge forming the outside of the meteorite, and it decreases in amount toward the contact between zones *A* and *B*. The veinlets of hematite, which have a maximum thickness of only 1 mm., are more continuous than those formed by the nickel-iron and pyrrhotite. Most of the longer veinlets are approximately parallel to the outer edge of the meteorite. Throughout zone *A*, the distribution of the minerals suggests fracturing of this part of the stone previous to the introduction of nickel-iron and pyrrhotite. It is also probable that the nickel-iron preceded pyrrhotite in time of crystallization.

Zone *B* is the central part of the meteorite. In it the arrangement and distribution of the mineral constituents are indicative of flow structure. This zone consists of a very fine-grained ground mass in which many of the minute particles of the metallic and non-metallic minerals are in alignment along lines of flowage. In the thin sections the alignment of small broken particles of pyroxene and olivine is less evident than the alignment of nickel-iron and pyrrhotite noticeable in the polished section. Three distinct veinlets of nickel-iron and pyrrhotite are parallel to the flowage lines in the wide part of the zone near the edge of the meteorite (Fig. 1A). A few veinlets of hematite are present in zone *B* but they are far less common than in zone *A*. The intricate network of minute veinlets of nickel-iron and pyrrhotite, which is so prominent in zone *A*, is absent in zone *B*.

Zone *C* with veinlets of nickel-iron arranged in a "horse-tail" manner adjacent to zone *B* (Fig. 1A), is another indication of flowage within the Lubbock meteorite. The "horse-tail" veinlets vary in width from 0.10 to 0.40 mm., and have a maximum length of 5.4 mm. They lose their identity as they approach the central mass of the zone which in general appearance is similar to zone *A*. The "horse-tail" arrangement of the nickel-iron veinlets suggests strongly that flowage caused fracturing of zone *C* adjacent to zone *B*, and that the fractures were slightly curved by dragging either before or after the deposition of nickel-iron. Pyrrhotite in this zone is present as minute particles some of which are arranged in veinlets. The network pattern of the veinlets is not, however, as pronounced as it is in zone *A*.

Conclusion

The flow structure and brecciation in the Lubbock meteorite, as indicated by the arrangement and distribution of the mineral constituents, probably occurred previously to its flight. Deposition of the nickel-iron and pyrrhotite, or at least a re-crystallization of these minerals, took place after some fracturing of the meteorite, as indicated by the veinlets traversing many of the olivine chondrules, and by the network of veinlets so well developed in zone *A*. Characteristics of the contacts between pyrrhotite and nickel-iron suggest that the nickel-iron preceded pyrrhotite in time of crystallization, or that it was partially replaced by pyrrhotite.

EXSOLUTION GROWTHS OF ZINCITE IN MANGANOSITE AND OF MANGANOSITE IN PERICLASE

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Abstract

Manganosite from Franklin, New Jersey, contains exsolved plates of zincite oriented with zincite {0001} [10$\bar{1}$0] parallel to manganosite {111} [011]. Periclase from Långban and Nordmark, Sweden, contains exsolved octahedra of manganosite oriented with periclase {111} [011] parallel to manganosite {111} [110]. The structural relations expressed in the orientations and the solid solubility of Zn in MnO and of Mn in MgO are discussed

Zincite Intergrowths in Manganosite

Manganosite, MnO, occurs at Franklin, New Jersey, as irregular masses up to 3 or 4 inches in size, associated with willemite, franklinite, coarse zincite, and calcite.[1] A pronounced octahedral parting is present in the larger masses, in addition to the cubical cleavage proper to the mineral. The parting surfaces are covered by a more or less continuous film or plate of zincite, about 0.05 to 0.25 mm. in thickness. Optical examination proves that the zincite plates are single individuals over their entire extent, and that they are flattened on {0001}. A series of cleavage cracks arranged at 60° are seen in the plates, together with rod-like and hexagonal plate-like inclusions arranged parallel to the cleavage directions. An *x*-ray Laue photograph verified the plane of flattening as {0001} and the cleavage as {10$\bar{1}$0}. The law of orientation of the two minerals was found to be zincite {0001} [10$\bar{1}$0] parallel to manganosite {111} [011].

Isomorphous Substitution of Zn in MnO and Mn in ZnO

Experimental data bearing on the substitution of Zn for Mn in MnO are lacking. Analyses[2] of the natural manganosite from Franklin show 3.41 and 4.89 per cent ZnO, but it is possible that the Zn is due to impurities. Co, Ni, Cd and Ca have been found[3] to substitute to varying extents for Mn in artificial MnO. The oxides of these metals, like MnO, form crystals of the NaCl-type. On the other hand, the isometric form of ZnO, although its predicted (ionic) radius ratio is within the range of the NaCl structure-type, forms crystals of the sphalerite-type.[4] This is apparently due to the relatively great tetrahedral bond-forming tendency of Zn. For this reason Zn would not be expected to enter, or at least be stable, within the 6-fold coordination of oxygen ions obtaining in MnO, in spite of the fact that its apparent ionic radius ratio does not differ from Mn as much as do Co, Ni, Cd and Ca. Nevertheless, Zn is present in natural MgO (periclase) from Nordmark, Sweden, in amounts ranging from 1.6 to 2.5 per cent ZnO,[5] although here again possibly due to admixture.

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[1] Palache, C.: *U. S. Geol. Survey, Prof. Paper* **180,** 37 (1935).

[2] Analyses cited in ref. 1, *loc. cit.*

[3] Natta, G., and Passerini, L.: *Gazz. chim. Ital.*, **59,** 129 (1929); see also ref. 11.

[4] Bragg, W. L., and Darbyshire, J. A.: *Trans. Faraday Soc.*, **28,** 522 (1932).

Divalent Mn enters zincite up to an apparent maximum of 6.5 per cent MnO, and divalent Fe is commonly present in small amounts.[2] Hexagonal, wurtzite-type, modifications of MnO and FeO are not known. Trivalent Mn also has been reported (<0.7 per cent Mn_2O_3) in zincite and is thought to cause the red color.[6]

The characters of the zincite growths as seen in polished sections[7] and in hand specimens exclude an origin other than by exsolution. A small solubility of Zn in MnO is thus indicated. This is estimated, from the relative volumes of the two minerals and assuming complete unmixing, at most as 15 weight per cent ZnO.

It may also be remarked that some grains of manganosite in transmitted light exhibit still further kinds of oriented microscopic inclusions, probably formed by exsolution: (1) an unidentified black lath-like mineral (Fig. 1) possibly identical with a gray mineral seen in polished section,[7] (2) hexagonal plates of hematite (?) (Fig. 1), and (3) prismatic crystals of a colorless anisotropic mineral that may be willemite. The zincite and willemite from Franklin also contain abundant oriented microscopic inclusions.

Structural Interpretation of the Orientation. The observed orientation between the zincite and the manganosite marks a position of complete coincidence of the crystal structures of the two minerals. Manganosite has a NaCl-type structure with $a_0 = 4.436$ Å, and zincite has a wurtzite-type structure with $a_0 = 3.242$ Å and $c_0 = 5.176$ Å. Manganosite viewed along [111] is composed of alternate layers of Mn and O ions stacked in cubic close packing, and zincite viewed along [0001] is composed of alternate layers of Zn and O ions stacked in hexagonal close packing.

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[5] Sjögren, H.: *Geol. För. Förh.*, **9**, 527 (1887).

[6] Dittler, E.: *Zeits. anorg, Chem.*, **148**, 332 (1925).

[7] Ramdohr (*Zbl. Min.*, p. 133, 1938) has also described manganosite from Franklin in polished section. He notes a minute oriented exsolution growth of an unidentified gray mineral (which is not zincite), and rims of zinc-hausmannite (=hetaerolite) on the manganosite grains. These features were also observed by the writer. Megascopic amounts of the so-called zinc-hausmannite were found on some specimens along the manganosite margins, and as penetrations along the partings on the sides of the zincite lamellae. *X*-ray powder pictures taken in comparison with hausmannite from Ilmenau and type hetaerolite proved the mineral to be hausmannite.

The actual O—O distances in MnO {111} and ZnO {0001} are 3.14 Å and 3.24 Å, respectively.

A mechanism of formation of the oriented growths is suggested by these facts. If, during the growth of a {111} face of MnO, Zn atoms occupy the positions adjacent to an O plane intended for Mn ions, a two-dimensional surface ZnO layer is formed on which are imposed the structural and dimensional characters of zincite. If growth continues by the deposition of additional layers of Zn and O ions, in the fashion of hexagonal close packing proper to zincite, an overgrowing three-dimensional zincite crystal is formed which is oriented by the law observed to the underlying MnO crystal. This mechanism may proceed upon the faces of a preformed MnO crystal (*oriented overgrowth*) or intermittently during the growth of a MnO crystal (*oriented syncrystallization*). Similarly, a MnO crystal containing Zn in isomorphous substitution for Mn may undergo environmental or other changes bringing a concentration and ordering of the Zn atoms, with the crystallization of ZnO as an exsolved phase again oriented upon the {111} planes.

A further illustration of the relation between packing scheme and orientation in ZnO and MnO is afforded by the films of (hexagonal) ZnO formed upon sphalerite when the latter is heated in air. Electron diffraction study[8] proves that the two substances are oriented with ZnO {0001} [$10\bar{1}0$] parallel to ZnS {111} [011]. This law is identical with that of ZnO—MnO, as would be expected since sphalerite along [111] is composed of alternate layers of Zn and S (=O) atoms essentially in cubic close packing. The ZnO film presumably is formed by the surface thermal dissociation of the ZnS with the substitution of O for S.

In all of these cases, the essential circumstance for the orientation of the one substance to the other is an identity or near-identity in structure between them. The identities tend to be shared, since the later-formed crystal can thus obviate the expenditure of energy in generating a free surface of its own kind.[9]

MANGANOSITE INTERGROWTHS IN PERICLASE

Periclase, MgO, occurs at Långban, Sweden, as uniformly colored grass-green irregular grains associated with hausmannite in a dolomitic marble.[10] The grains have brucite rims. Cleavage fragments examined in transmitted light under moderate magnification are seen to contain hosts of minute octahedra of manganosite (Fig. 2). The manganosite octahedra are all oriented to the periclase so that manganosite {111} [011] is parallel to periclase {111} [011].

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[8] Aminoff, G., and Broomé, B.: *Nature*, **137**, 995 (1936). See also Seifert, H.: *Zeits. Kryst.*, **102**, 183 (1940).

[9] Frondel, C.: *Am. Jour. Sci.*, **30**, 51 (1935).

[10] Sjögren, H.: *Geol. För. Förh.*, **17**, 288 (1895); **20**, 25 (1898).

An identical occurrence at Nordmark, Sweden, has been described.[5] Bulk analyses of this intergrowth show 7.0 to 9.1 per cent MnO.

It has been found[11] experimentally that MnO can enter MgO up to about 26 mol per cent MnO, and that Mg can enter MnO up to about 31 mol per cent MgO. An origin by exsolution of the present occurrences would indicate that the (quenched) artificial preparations were in unstable equilibrium. The periclase from Långban probably still contains some Mn in solid solution, for it has $n_{\text{Na}}=1.7425\pm0.0005$ while pure MgO has $n_{\text{Na}}=1.7360$. Assuming that the increase is due to MnO and that the index varies linearly between $n_{\text{Na}}=1.7360$ for MgO and $n_{\text{Na}}=2.18$ for MnO,[12] then the observed index corresponds to about 2 mol per cent MnO. This may be a saturation value for ordinary conditions.

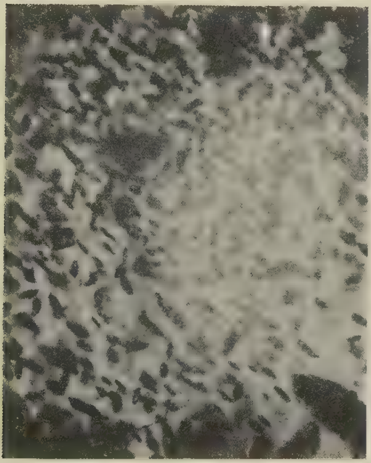

FIG. 1 (*left*). Oriented lath-like exsolution growths of an unknown black mineral and of hexagonal plates of hematite (?) in manganosite. Section parallel {111} of manganosite. Oil immersion, 425×.

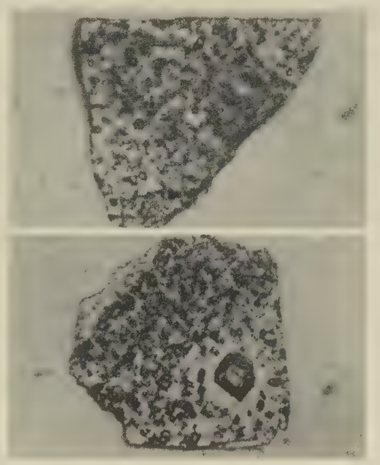

FIG. 2 (*right*). Oriented exsolution growths of manganosite octahedra (some distorted by elongation) in periclase. Note clear area around the large manganosite crystal; this is characteristic. Periclase grains are resting on {100} cleavages. 140×.

A complete structural and close dimensional resemblance exists between manganosite and periclase. Both have a NaCl-type structure, with periclase $a_0 = 4.203$ Å and manganosite $a_0 = 4.436$ Å. Manganosite hence may crystallize from a periclase environment without regard to the habit of the exsolved crystals, since any habit would maintain a structural coincidence with the MgO host crystal. Zincite, on the other hand, by reason of its only partial resemblance to manganosite, is forced to develop a particular habit when crystallizing within MnO in order to make contact with the particular plane of the MgO in which the structural resemblance exists. A similar geometrical control of nucleation is found in certain types of oriented adsorption layers on the surface of crystals.[13]

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[11] Passerini, L.: *Gazz. chim. Ital.*, **60**, 535 (1930).

[12] Ford, W. E.: *Am. Jour. Sci.*, **38**, 503 (1914); calculated from the measured indices, n_{red} 2.16 and n_{green} 2.19.

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[13] Frondel, C.: *Am. Mineral.*, **25**, 338 (1940).

THERMAL DECOMPOSITION OF ARSENOPYRITE

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One phase of a recent investigation of the crystal structure of arsenopyrite, which has been described elsewhere,[1] was an attempt to cause a high temperature order-disorder inversion from the arsenopyrite unit cell to one of the marcasite type. The attempt was unsuccessful because the mineral decomposed. It was felt, however, that the decomposition and its theoretical implications were worth reporting.

The arsenopyrite used in the investigation was from Spindelmuhle and from a specimen believed to have come from Saxony. In the early part of the work, small single crystals suitable for rotation photographs were used. The term "single crystal" is misleading as optical evidence later showed that what appeared to be single crystals were in reality built up of polysynthetic twins.[2,3] When it became apparent that no inversion could be brought about below the decomposition temperature, it was decided to determine approximately what this temperature was. For convenience, powdered material was used.

The samples were sealed in evacuated silica tubes and heated in an electric furnace which could be maintained at a uniform temperature. Various temperatures and periods of time were tried in the attempt to bring about the inversion. Table 1 is compiled from the data recorded:

TABLE 1

Locality	*Temp (°C)*	*Time*	*Form*	*Result*
Spindelmuhle	543	4h 10m	Crystal	No effect
Saxony (?)	597	3h 0m	Powder	No effect
Spindelmuhle	646	0h 15m	Crystal	Partial decomp.
Saxony (?)	657	2h 47m	Powder	No effect
Saxony (?)	707	2h 57m	Powder	Decomposition
Saxony (?)	738	2h 45m	Powder	Decomposition
Saxony (?)	849	2h 57m	Crystal	Decomposition
Saxony (?)	852	0h 16m	Crystal	Decomposition
Saxony (?)	856	167h 31m	Crystal	Decomposition
Spindelmuhle	857	0h 15m	Crystal	Decomposition
Spindelmuhle	857	2h 25m	Crystal	Decomposition

The experiments were not performed in order of increasing temperatures as listed in the table. In general, the higher temperature tests were made first.

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[1] Buerger, M. J.: *Zeits. Krist.* (A), **95**, 83–113, 1936.

[2] Buerger, M. J.: *Op. cit.*

[3] Buerger, M. J., and Lukesh, J. S.: *Am. Mineral.*, **21**, 667–669 (1936). See Fig. 4, p. 669.

It can be seen from the table that the decomposition begins to be detectable at about 650°C. The apparent inconsistency occasioned by the fact that a crystal from Spindelmuhle was partially decomposed after fifteen minutes of heating at 646° and powder from Saxony (?) was unaffected at 657° after two and three-quarter hours may perhaps be due to variations in composition. Unfortunately, no analyses of the materials are available. All of the temperatures recorded above were measured with a thermocouple whose cold junction was kept at room temperature, and hence the values are not precise.

Rotation photographs taken before and after heating the single crystals showed that essentially a powder resulted. In cases of low temperatures and short periods of time, the outward appearance of the crystals was unchanged except for a microscopic pitting. Crystals which were heated at high temperatures for long periods of time were actually separated into two components. The same was true of all of the powdered material which was affected at all. One of the products of decomposition was in the form of silvery hexagonal plates, and the other consisted of yellowish, non-magnetic lumps. When crystals were used, the yellow material was in apparently residual lumps, left after the distillation of the other component; when powder was used, the yellow component was in the form of very small, well-formed crystals.

Powder photographs of the two components were taken and compared with those of all possible decomposition products as well as the original arsenopyrite. It is clear from a brief consideration of the composition of arsenopyrite and from the fact that it was heated in the absence of air that there are only four possible products: pyrite (at the temperatures involved marcasite is unlikely), löllingite, pyrrhotite, and arsenic. The reaction could proceed in one of two ways:

$$2FeAsS \longrightarrow FeS_2 + FeAs_2 \qquad (1)$$

or

$$FeAsS \longrightarrow FeS + As \qquad (2)$$

The composition of arsenopyrite is known to be highly variable;[4,5] the formula can be written $Fe_xAs_yS_z$ where x, y and z are approximately equal to one. A departure from the ideal composition of the original material would, of course, have an effect on the end products. Of the two alternative reactions, the more probable should be that in which such variations could be more easily accommodated. Greater flexibility is offered in reaction 2, pyrrhotite being highly variable and the amount of arsenic being unlimited. The reaction would be: $Fe_xAs_yS_z \rightarrow Fe_xS_z + yAs$. Actually, comparison of powder photographs identified the silvery

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[4] Doelter, C., and Leitmeier, H.: *Handbuch der Mineralchemie*, Bd. IV, Erste Hälfte, Dresden and Leipzig, 610–618 (1926).

[5] Buerger, M. J.: *Op. cit.*

hexagonal plates as arsenic and the yellow material as pyrrhotite (see Figs. 1 and 2).

Since no analyses of the materials used are available, no values can be assigned to x and z. Some indication of the relative proportions of iron and sulfur can be obtained, nevertheless, from the fact that the material identified as pyrrhotite was non-magnetic. On the basis of the work of the Geophysical Laboratory of the Carnegie Institution,[6,7] where it was shown that low temperature pyrrhotite containing less than about seven molecular per cent excess of sulfur is non-magnetic, it would seem that the iron and sulfur are present in about the proportions 1:1. (Hägg and Sucksdorff[8] have shown through density considerations that actually variations in composition of pyrrhotite are due to a deficiency of iron rather than an excess of sulfur.) In the present experiments, however, the pyrrhotite was formed at relatively high temperatures. Newhouse[9] made

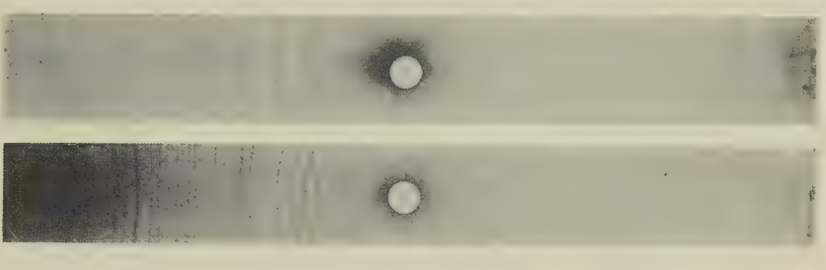

FIG. 1. (Top) Natural pyrrhotite from Cold Springs, New York. (Bottom) Undistilled residue from Saxony (?) arsenopyrite heated to 738°C.

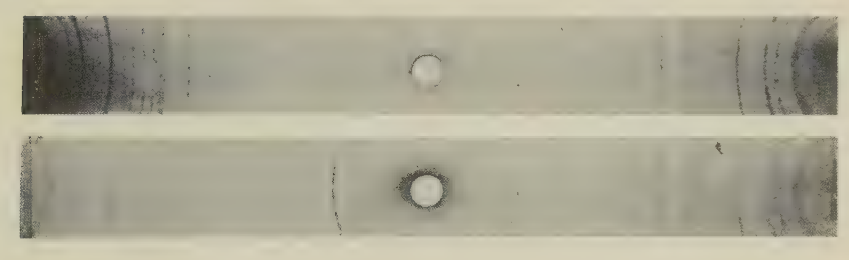

FIG. 2. (Top) Recrystallized part of Saxony (?) arsenopyrite heated to 738°C. (Bottom) Arsenic.

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[6] Merwin, H. E., and Lombard, R. H.: *Carnegie Inst. of Wash. Yearbook*, **30**, 82–84 (1931).

[7] Roberts, H. S.: *ibid.*, 84–85.

[8] Hägg, G., and Sucksdorff, I.: *Zeits. physik. Chem., Abt. B*, **22**, 444–452 (1933).

[9] Newhouse, W. H.: *Ec. Geol.*, **22**, 288–299 (1927).

synthetic pyrrhotite at high temperatures and found it to be magnetic. Merwin and Lombard[10] showed that pyrrhotite produced at high temperatures with the ratio $z:x$ varying from 1.18 to 1.002 are all magnetic with, apparently, the magnetic strength decreasing as the ratio $z:x$ falls. In all probability, the material produced in the present experiments contains iron and sulfur in nearly the stoichiometric ratio for the true monosulfide of iron. There is, however, no reason to exclude the possibility of an excess of iron as some samples of arsenopyrite are known to have a ratio of iron to sulfur greater than one. Doelter and Leitmeier[11] cite an analysis in which the molal ratio of iron to sulfur is .652 to .480.

The non-magnetic form of the monosulfide of iron is usually called troilite. There is some question whether it is an end-member of the pyrrhotite series or a distinct species. Eakle[12] examined some natural troilite and found it to be considerably different from pyrrhotite in magnetic properties and in its reaction to sulfuric acid. Troilite was non-magnetic and dissolved easily in the acid, while pyrrhotite was magnetic and difficultly soluble in acid. He considered that these differences were too great to be accounted for on the basis of composition alone and decided that troilite was a distinct species. The chemistry of the crystals formed in the present experiment was not investigated so it is not possible to compare results. It is not possible to draw conclusions from so little evidence, but one can point out that the crystals resembled troilite in being non-magnetic and gave the same diffraction pattern as pyrrhotite.

A. Beutell[13] first reported the decomposition of arsenopyrite, but he does not specify the temperature other than "dark red heat."

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[10] Merwin, H. E., and Lombard, R. H.: *Ec. Geol.*, **32**, 203–284 (1937). See especially p. 258.

[11] Doelter, C., and Leitmeier, H.: *Loc. cit.*

[12] Eakle, A. S.: *Am. Mineral.*, **7**, 77–80 (1922).

[13] Beutell, A.: *Zbl. Min.*, etc., 316–320 (1911).

CORDIERITE GRANITE FROM TERIP TERIP, VICTORIA

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Introduction

The occurrence of cordierite granite at Terip Terip (Fig. 1), in the parish of Dropmore, County of Anglesey, is of interest in view of the rarity of this variety of granite (4, p. 241). Cordierite has previously been recorded in Victorian granitic rocks from Bulla (6, p. 244), Trawool (6), Marysville (3, p. 149) and North-Eastern Victoria. In none of these occurrences is the cordierite developed in such abundance as at Terip Terip.

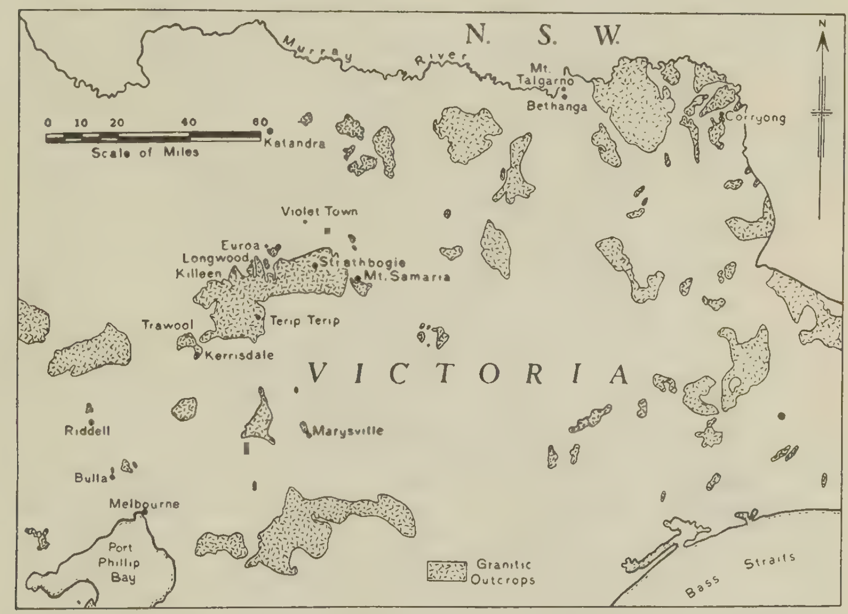

Fig. 1. Sketch map of portion of Victoria (eastern portion), showing granitic outcrops, and localities mentioned in connection with cordierite occurrences.

Description

The Terip Terip granite is light gray in colour and porphyritic. Phenocrysts of orthoclase, up to one and a half inches long, are set in a more or less medium, even-grained base of quartz, orthoclase, oligoclase, biotite and cordierite, as shown in Fig. 2.

The cordierite occurs as abundant bluish-gray patches, with the crystals often 10 mm. long. Most of the cordierite, especially the smaller crystals, has been altered to muscovite, chlorite, and greenish micaceous products regarded as pinite, but in occasional larger crystals, residuals of clear, unaltered cordierite occur within these alteration products. The clear, colourless portions of the cordierite are optically biaxial and negative. Low polarising fibrous aggregates, which occur along cracks in the outer parts of some of these larger crystals, probably consist of serpentine. Some of the pseudomorphs of secondary products developed after the cordierite show fibrous, radiate and plumose structures. The alteration commenced around the edges of the crystals, and has penetrated along irregular cracks and poorly defined pinacoidal cleavages. Part of the pale greenish-yellow coloured products along some of the cracks and in the outer zones of larger crystals, is isotropic.

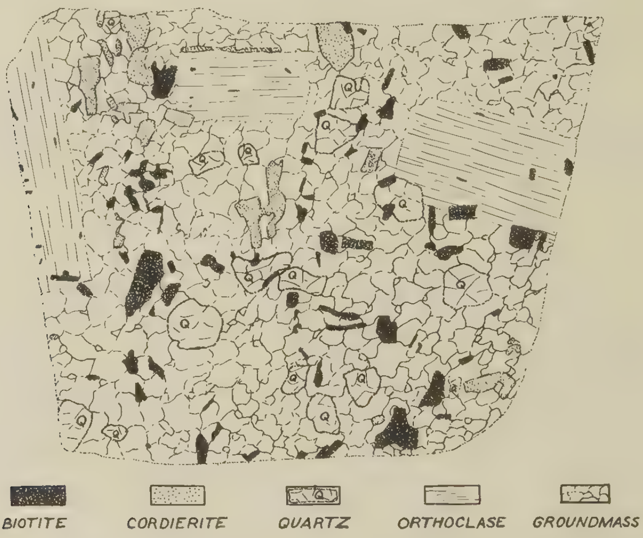

FIG. 2. Sketch of polished specimen of cordierite granite from Terip Terip.
(Sketch enlarged one and one sixth times natural size.)

Occasional partially altered, small crystals are pseudo-hexagonal in cross section and show sector twinning, while simple twins are also present in sections parallel to the long axes of the crystals. Small crystals of zircon and apatite are included in the cordierite, and pleochroic haloes produced around the zircons are more pronounced where the cordierite has been altered to secondary products.

The cordierite apparently crystallised prior to quartz and orthoclase, as it is often embayed by these minerals, and where euhedral, it has these later formed minerals moulded around it. Many of the cordierite crystals, however, are anhedral, and their relationships to the other minerals are not clear.

The cordierite-bearing granite from Terip Terip shows other distinctive features in that the quartz is sometimes poikilitic, and sometimes occurs as pools in optical continuity. These pools are more common in the base of the rock, but are occasionally found within the larger cordierite crystals as vermicular growths. The orthoclase is microperthitic, poikilitic, and often cloudy from deuteric alteration, and the oligoclase is partially sericitised. Muscovite occurs as secondary aggregates, radially arranged plates and larger separated flakes. It is common throughout the rock, and often forms the outermost fringe of the altered cordierite crystals.

A Rosiwal micrometric analysis, using 2 mm. traverse intervals across sixteen thin sections of the Terip Terip cordierite granite, shows the main minerals to be present in the following proportions:

TABLE 1

Quartz	29.9%
Orthoclase	34.1
Oligoclase	19.1
Cordierite	6.8
Biotite	6.5
Muscovite	3.6

Except for muscovite, the alteration products of the cordierite were measured in with the cordierite. Biotite and cordierite are present in almost equivalent amounts, while the dominance of orthoclase over plagioclase feldspar indicates that this rock belongs to the granite family. It is a potash rich, two-mica cordierite granite.

The accessory minerals consist of zircon, apatite, ilmenite, rare colourless garnet, and rare purplish-blue fluorite which occurs along the cleavage directions in biotite. Two very rare accessory minerals observed in the heavy mineral suite, but not in thin sections, are tourmaline and anatase. The heavy mineral index number (i.e., the ratio of heavy to light minerals, using bromoform of specific gravity 2.88) is 6, and the specific gravity of the rock is 2.63. The heavy mineral assemblage is composed mainly of biotite.

COMPARISONS OF THE TERIP TERIP CORDIERITE GRANITE WITH OTHER OCCURRENCES CONTAINING CORDIERITE IN VICTORIA

In addition to the occurrences of cordierite at Terip Terip, the author has discovered this mineral in the granitic rocks from Longwood, Kerrisdale, Killeen, Euroa, Mt. Samaria, Violet Town and Strathbogie, which are all part of the same mass as the Terip Terip and Trawool granites (Fig. 1). Cordierite also occurs in a tourmaliniferous granite dyke at Katandra, about forty miles north of Euroa.

The nature of the cordierite varies somewhat throughout this large intrusion of granite, which may be designated the Strathbogies Mass. Some of the Longwood occurrences show an apparent lamellar twinning which is absent from the Terip Terip examples. In the Kerrisdale rock, all of the cordierite has been completely altered to pseudomorphs of pinite. The occasional crystals of cordierite in the Trawool specimens are sometimes larger and fresher than the majority of the Terip Terip crystals. Pinacoidal cleavages are more pronounced in the cordierite of the Bulla and Trawool granitic rocks than in any of the others.

In all of these rocks, the cordierite crystals are almost free from inclusions of biotite and iron oxides. In the highly contaminated granitic rocks containing cordierite from Bethanga and Mt. Talgarno in North-Eastern Victoria (7), however, biotite plates are abundant throughout the cordierite crystals.

ORIGIN OF THE CORDIERITE

The source of the constituents forming the cordierite in the Terip Terip granite probably lies in altered argillaceous sediments of Silurian age, since spotted cordierite hornfels forms the wall rock of the intrusion in this area. In view of existing analyses of Silurian shales in Victoria, these contact sediments are probably potassic.

In these thermally altered contact rocks, the cordierite contains numerous small, included plates of biotite. In highly contaminated granitic rocks such as those from North-Eastern Victoria, biotite inclusions in the cordierite are larger, but are not as numerous. It would therefore appear that the cordierite in these highly contaminated granitic rocks was xenocrystal in nature, like those in certain of the English Dartmoor granites (1, p. 189), and that clarification of impurities from the crystals was incomplete when crystallisation occurred.

Two modes of origin can be postulated for the cordierite crystals in the Strathbogies Mass, which are nearly free of such inclusions. (1) They may be xenocrysts derived from the mechanical disruption of cordierite-bearing xenoliths. Owing to the slow cooling of the granite, the cordierite crystals may have been able to almost clear themselves of the biotite inclusions. Against this supposition, the arguments may be advanced that as far as the various specimens from the Strathbogies granitic mass are concerned, no intermediate stage in this "clearing" process, and no xenoliths in a state of partial disintegration have been observed in the cordierite-rich granite. (2) The other possibility is that the cordierite crystals are of pyrogenetic origin (1, p. 189), and have resulted from the enrichment of the granite magma in alumina by the assimilation of aluminous, argillaceous country rock. In favour of this possibility, is the tendency towards euhedral outline of many of the crystals.

It is not possible to arrive at any proof as to which of these modes of origin is the correct one, but the author is inclined to favour a pyrogenetic origin, in view of the arguments noted above.

The various degrees of alteration of the cordierite have resulted from the subsequent introduction of variable amounts of alkaline material from the magma. The pseudomorphs of secondary pinite, represent incomplete stages in the alteration of the cordierite to muscovite, of which mineral, pinite is a massive variety, stained pale yellowish-green in colour by the liberation of small amounts of iron from the cordierite. As chlorite is a secondary alteration product of biotite as well as of cordierite, it cannot be ascertained with any degree of certainty, how much of the chlorite in the rock is produced from biotite, and how much from cordierite. The only indication of the original mineral it was developed from, is provided by such crystals as retain the basal cleavage directions of biotite.

From the mode of alteration of cordierite in these granitic rocks, it would appear that Harker's formula: sericite+chlorite+iron=cordierite+biotite, as applied to the thermal alteration of argillaceous rocks (2, p. 50), is reversed when cordierite breaks down in the magma under the influence of alkaline solutions. Much of the secondary mica so formed has in large part been dispersed in the magma, and by mingling with the primary micas, has lost its identity of origin.

Conclusions

That cordierite is generally a rare constituent of granitic rocks, is borne out in Victoria by the fact that the examination of over 300 sections of granite and granodiorite, from over 100 localities in different parts of the State, has revealed this mineral in only four outcrops, namely (*a*) Bulla (6), (*b*) Marysville (3), (*c*) Bethanga and Mt. Talgarno in North-Eastern Victoria (7), and (*d*) the Strathbogies Mass (Terip Terip, Trawool, etc.).

Tattam considers that cordierite is probably never primary in granitic rocks, and that the cordierite in the Bulla and Trawool rocks is unique in occurrence (6, p. 247), but he adds that traces of its existence could be found in many other masses where the contact rocks contain this mineral. The only Victorian granitic rocks to indicate the probable presence of pinite pseudomorphs after cordierite, besides those already shown to possess cordierite as fresh or altered crystals, are from Riddell and from Corryong (Fig. 1). In these two rocks, there are no definite crystals of cordierite like those at the localities mentioned above.

The widespread and abundant occurrence of cordierite in the Strathbogies Mass is indicated by its presence in practically every section examined from this outcrop. Most of the localities referred to in this mass are along the contact with Silurian sediments that have been subjected to marked thermal metamorphism, especially along the southern boundary of the granitic massif (5, p. 297). One or two of the localities examined, however, are situated well within the granite mass, and there is little doubt that many other localities within the Strathbogies Mass, would reveal the presence of cordierite.

This widespread occurrence of cordierite throughout the large and texturally variable granitic outcrop of the Strathbogies, and the close association of argillaceous wall rock around the boundaries of the intrusion, suggest that there has been a wide and fairly constant process of assimilation of lithologically similar country rock by this batholith, resulting in relatively even contamination of the granitic rock over a wide area.

Tattam regards the cordierite in the granitic rocks from Bulla and Trawool as indicating contamination (6, p. 245), and this view is considered to be correct for all of the Victorian cordierite-bearing granitic rocks so far discovered, where the cordierite occurs either as xenocrysts or as products of crystallisation from a contaminated magma.

An effect of the assimilation of the argillaceous contact rock (potash rich), from which the cordierite was developed, has been to enrich the granite in alumina and potash (combined in muscovite), as exemplified by marginal occurrences in the Strathbogies Mass.

ACKNOWLEDGMENTS

The author is indebted to H. B. Hauser, M.Sc., for making available the contact rock and granite specimens collected by him from the Terip Terip District, and to Dr. W. J. Harris, for specimens from a granite dyke at Katandra.

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NOTES AND NEWS

NOTES ON SOME MINERALS FROM SOUTHERN CALIFORNIA. II*

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Introduction

In this paper have been grouped a number of brief descriptions of new mineral localities in southern California, and observations on some localities previously described. It is the intention of the writers to publish similar assembled data from time to time, in the hope that in this way the information may be made more readily available than if issued as separate items.

Inyoite Crystals from Death Valley

Fresh inyoite crystals in a cavity with the usual meyerhofferite pseudomorphs were recently collected from the classic locality originally described by Schaller[1] from Mt. Blanco, Death Valley, Inyo County, California. The specimen contained three transparent crystals, the largest of which was one-half cm. in its greatest dimension. Measurements on the two-circle goniometer gave specific determinations of crystal forms which were unobtainable at the time Schaller published his paper. These are apparently the first inyoite crystals found at this locality on which accurate measurements could be made. The writers wish to thank Mr. and Mrs. V. D. Myers of Santa Monica who collected the material, for giving the crystals for study.

In Table 1 are given the measured and calculated values for the forms present.

Table 1

Letter	*Symbol*	*Measured*		*Calculated*	
		ϕ	ρ	ϕ	ρ
m	110	51°13′	90°00′		
		51°90′	90°00′		
	Average	51°11′	90°00′	51°06′	90°00′
p	111	62°06′	56°01′		
		61°58′	56°01′		
		62°01′	56°08′		
	Average	62°03′	56°03′	62°00′	55°57½′

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* Notes on some minerals from southern California: *Am. Mineral.*, **23,** 349–355 (1938).

[1] Schaller, Waldemar T., Inyoite and meyerhofferite, two new calcium borates: *Mineralogic Notes* (3) *U. S. Geol. Surv., Bull.* **610,** 35–55 (1916).

TABLE 1 (*continued*)

Letter	*Symbol*	*Measured*		*Calculated*	
y	$\bar{1}11$	31°22′	39°00′	30°53½′	39°00′
c	001	90°00′	24°09′		
		90°00′	24°03′		
		90°00′	24°12′		
	Average	90°00′	24°08′	90°00′	24°01′
b	010	−0°02′	90°00′	0°00′	90°00′

The crystallography of inyoite has been accurately determined by Poitevin[2] on crystals of translucent inyoite in crevices in massive gypsum from the Whitehead Quarry, Hillsboro, New Brunswick. The crystals from this locality were more complex, showing 12 forms compared to the 5 forms on those from Death Valley.

CELESTITE AND BARITE NODULES FROM AVAWATZ MOUNTAINS, SAN BERNARDINO COUNTY

Irregular concretionary masses of celestite with some barite included, occurring in gypsiferous clay shales, are found in manganese deposits at the west end of the Avawatz mountains, San Bernardino County, California, at Owl Hole Spring, T. 27 S., R. 3 E., Avawatz Quadrangle. The nodules have a distinct cauliflower appearance. The celestite, which composes the major part of the nodules, is massive, snow white and sugary. It is stained slightly in spots with a small amount of limonite, but large areas of pure celestite are common. Sectioning of the concretionary masses shows no megascopic structure internally.

The manganese deposit with which these nodules are associated was described briefly by Mann,[3] who outlined the general stratigraphic setting as a sedimentary sequence of Jurassic (?) lake beds, limestones, gypsum, and shale, approximately 1000 feet thick. In the sedimentary section pyrolusite is found. The shales of the lake beds contain the concretionary masses of celestite. The mode of origin and source of the strontium is unknown, but it may have been concentrated by circulating ground water from the gypsiferous shales. The nodular masses are apparently similar to those of strontianite and calcite found in an area to the south which has been described by Knopf,[4] where, however, celestite is found only as microscopic constituents of recrystallized limestone and small glassy crystalline aggregates.

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[2] Poitevin, Eugene, and Ellsworth, H. F., Inyoite from New Brunswick: *Canada Geol. Surv., Bull.* **32,** 1–8 (1921).

[3] Mann, R. L., Owl Head manganese deposit, San Bernardino County, California: *Mining World,* **44,** 743–744 (1916).

[4] Knopf, A., Strontianite deposits near Barstow, California: *U. S. Geol. Surv., Bull.* **660,** I, 263 (1918).

CALCITE NODULES FROM MOJAVE WATER CAMP, SAN BERNARDINO COUNTY

About one-half mile north of Mojave water camp, on the Barstow-Needles highway, is a deposit of bentonite probably in the Manix beds of Pleistocene age.[5] In this bentonite, is an abundance of nearly spherical concretions ranging in size from an inch up to three or four inches in diameter. On being broken open, these are seen to be made up of calcite, in radial crystalline grains, and showing concentric "growth rings." They are usually solid, but occasionally the center shows a small vug, lined with calcite crystals.

SAND CALCITE CRYSTALS, RED ROCK CANYON, KERN COUNTY

Calcite crystals with inclusions of sand grains up to 65% of their volume, and known as "sand calcite," have long been known, originally from Fontainebleau,[6] and in this country from Rattlesnake Butte,[7] near Interior, South Dakota. Similar examples were found in Monterey County, California, in the Cholame Hills, and were described by Rogers and Reed.[8] These showed only the negative rhombohedron $(02\bar{2}1)$, sometimes as four-fold cyclic twins, and averaged 65% sand content.

Sand calcite crystals have also been found in Red Rock Canyon, California, just north of Ricardo. They occur here in a rather incoherent sandy layer interbedded with the series of pyroclastics of the region. The crystals vary from one-quarter to one-half inch in size up to short stout prisms as much as one inch across. Some are separate individuals, but usually they occur in clusters or irregular aggregates with no apparent crystallographic relationship. The dominant form is the prism, and this is usually terminated by a rounded end, although rarely a suggestion of a rhombohedron may be detected. Relatively few have clearly developed prism faces, and from this they grade downward, increasingly imperfect and vague, to rounded concretionary aggregates showing no crystal form whatever. The steep scalenohedron, so typical of the South Dakota locality, is entirely absent here.

The amount of sand inclusion, roughly determined by dissolving the calcite in dilute acid, is approximately 64%.

[5] Ellsworth, E. W., and Blackwelder, Eliot, Pleistocene lakes in the Afton Basin: *Am. Jour. Sci.*, (5) **31**, 453–463 (1936).

[6] Haüy, C.: *Traité de Mineralogie*, **2**, 184 (Paris, 1801).

[7] Wanless, H. R., Notes on sand calcite from South Dakota: *Am. Mineral.*, **7**, 83–86 (1922).

[8] Rogers, A. F., and Reed, R. D., Sand calcite crystals from Monterey County, California: *Am. Mineral.*, **11**, 23–28 (1926).

ADDITIONAL NOTE ON VEATCHITE FROM TICK CANYON, LOS ANGELES COUNTY

Another visit to the borax mine at Lang was attended with better success than the first, and a number of specimens of this rare and newly described[9] borate were obtained. The mode of occurrence in these is somewhat different from any previously described. The mineral occurs in thin seams cutting a fine blue-gray clay along irregular fractures. It runs in flat lying individuals which show their pearly cleavage when the rock is split along one of these fractures, and not in cross fiber structure. Usually associated with it are similar seams of colemanite, but the pearly luster and two cleavage directions are sufficient to distinguish it from the latter. A particularly favorable location is in a rather thick layer of pure clay, between thin-bedded dark-gray stained layers which are high in lime. All material was found in boulders on the dump, as it is impossible to get safely into the workings of the mine.

RHODONITE, CAJON PASS, SAN BERNARDINO COUNTY

During field work in connection with the occurrence of alurgite,[10] in the Cajon Pass area, several boulders of rhodonite were found in the alluvial deposits on the summit of the pass. These boulders were black, and massive, and upon opening were found to consist of cores of pink rhodonite, oxidized outward more and more completely to psilomelane. Associated with the rhodonite were boulders of psilomelane which contain needles of a sub-metallic mineral, which was identified as manganite. Material may be collected from any of the ravines running in a northeasterly direction from the Cajon Pass fan, although the boulders are far from abundant.

AXINITE

Two new localities of plum-colored axinite have been visited recently, in rather widely separated areas. In one area, the axinite is abundant in irregular and bladed crystalline masses; in the other, it occurs as subhedral grains and imperfect small crystals. Yet a third locality near Woody, Kern County, California, has been reported but as yet unverified.

Erskine Creek, Piute Mountains, Kern County

A large contact zone between quartz monzonite and metamorphic rocks in the southern part of the Kernville quadrangle, Kern County, contains abundant irregular masses and bladed subhedrons of plum-colored to brownish-blue axinite. The locality is specifically on the south fork of Erskine Creek, in T. 28 S., R. 33 E., sec. 6, Kernville quadrangle.

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[9] Switzer, George, Veatchite, a new calcium borate from Lang, California: *Am. Mineral.*, **23**, 409–411 (1938); Murdoch, Joseph, Crystallography of veatchite: *Am. Mineral.*, **24**, 130–135 (1939).

[10] Webb, Robert W., Investigation of a new occurrence of alurgite from California: *Am. Mineral.*, **24**, 123–129 (1939).

The contact zone varies from 1 to 6 feet in width; along it has developed a massive tactite, with epidote, garnet, diopside, axinite, calcite, quartz, and orthoclase in irregularly distributed sub- to anhedral grains. Large crystalline masses of axinite occur, with long bladed masses showing a few faces. Optical examination of the axinite showed the usual properties.

The metamorphic rocks in which the mineral occurs consist chiefly of mica schists, little quartzite, and much marble, although marble is subordinate at the actual contact. A fuller description of these rocks and the associated quartz monzonite intrusive will be found in another paper.[11]

Rademacher-Terese, Inyo County

A deposit of wollastonite in large masses of crystalline limestone has been known for sometime to occur between Terese and Rademacher sidings, on the Southern Pacific (Owenyo Branch) Owens Valley line, Inyo County, California, in T. 27 S., R. 39 E., Searles Lake quadrangle. Recently, while collecting in this area, contact zones in the marble were seen in which calcite and epidote were hosts to subhedral grains of plum-colored axinite. The axinite looks almost exactly like that found at Crestmore, in Riverside County, California.

GARNET AND EPIDOTE NEAR DAGGETT, SAN BERNARDINO COUNTY

Alluvial fans just to the south of Daggett, California, carry boulders of an amygdaloidal lava, which in some instances contain a rather interesting combination of minerals in the amygdules. The lava is basaltic in character, very fine-grained and dark, weathering to a purplish-gray on the exposed surfaces. The amygdules are filled with epidote, in radiating prismatic aggregates. No terminated crystals were seen, but in some cases the cavities were incompletely filled. In a few cases, calcite is associated with the epidote, deposited on its surface, and in such cases a number of honey-colored grains were seen embedded in the calcite, or perched on the surface of the epidote. On examination with a hand lens, these were seen to be euhedral crystals of garnet, showing the single dodecahedron. The index of refraction of this garnet was determined to be well over 1.75, and is presumably almandite. This occurrence of garnet in the vesicles of a lava is rather unusual, and worthy of attention.

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[11] Miller, W. J., and Webb, R. W., Descriptive geology of the Kernville quadrangle, California: *Calif. Jour. Mines and Geology* (in press).

Some of the lava cavities are lined with thin specularite flakes, none of which was found in combination with the other minerals, so that the age relationships could not be determined.

Fayalite in Spherulites from Inyo County

Near Coso Hot Springs, Inyo County, there is an occurrence of lithophysae in obsidian, which has been described by Rogers.[12] The writers have collected considerable material obviously from the same locality and wish to add some observations to those previously reported.

The material occurs in an obsidian flow on a steep hillside, a few miles west of Coso Hot Springs, and can be reached easily by a road branching eastward from the Owens Valley highway just north of Little Lake. The lithophysae are very numerous in some portions of the rock, ranging up to one and a half inches in diameter. Most of them are quite regular, nearly spherical in outline, showing little sign of stretching, and in large part they are almost solidly filled. Where cavities occur, they may be irregular central openings, or more commonly meniscus shaped gaps between layers of the concentric structure. On the walls of such cavities, as Rogers notes, there are minute spherulites of cristobalite which in many cases are crusted over with platy crystals of tridymite. In addition, the writers found some of these spherical aggregates to be made up entirely of tridymite plates. The radial and concentric structure which he mentions is in some cases very pronounced, and often spotted throughout with nodes of apparently structureless material. Rogers mentions these, and suggests that they were incipient spherulites. In the more solid lithophysae, the central portions are ordinarily quite dense, whereas the center parts, especially near the cavities, are very friable, and consist apparently of the radial rods or fingers of orthoclase (Rogers, p. 214).

Rogers (p. 215) notes minute tabular crystals of fayalite. The writers have observed crystals up to 3 mm. across, and by observation and goniometric measurement have recorded the following forms: (100) most prominent, modified by narrow development of (101) (010) (120) (021) (111); rarely other prism faces, as (110) (230) (130) (140); occasional pyramids (121) (131) and very rarely, faces in the zone (111)/(100), poorly developed, but giving positions corresponding fairly well to (322) and (211). These did not give satisfactory signals, and should be regarded as doubtful forms.

Some of the lithophysae were ruptured, with cracks extending to the outer surface, producing a curious explosion effect which is shown in the accompanying photograph.

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[12] Rogers, A. F., A new occurrence of cristobalite in California: *Jour. Geol.*, **30**, 211-216 (1922); Natural history of the silica minerals: *Am. Mineral.*, **12**, 76 (1928)

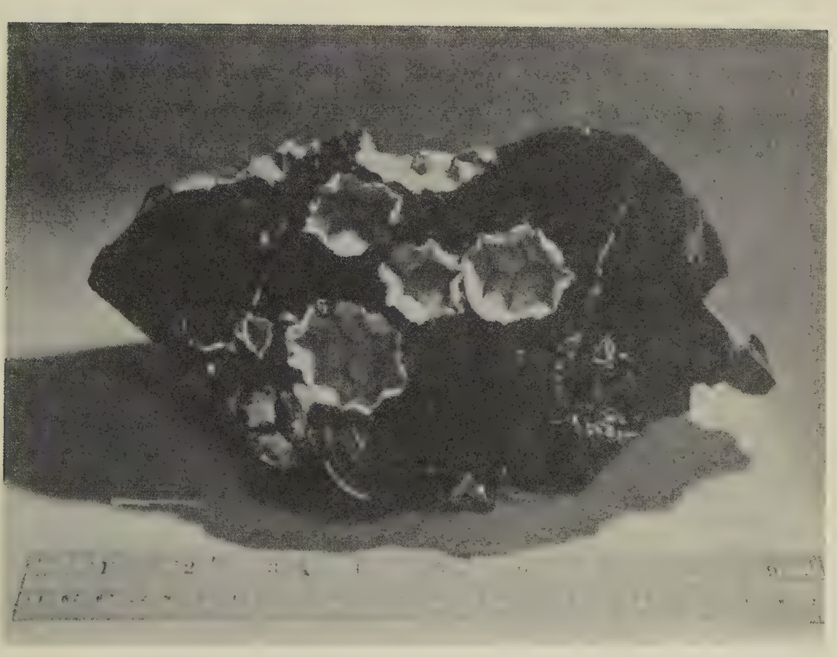

Fig. 1. Exploded lithophysae in Obsidian.

OCCURRENCE OF MILLERITE AT MILWAUKEE, WISCONSIN

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Millerite, NiS, belongs to the rhombohedral class of the hexagonal system. The metallic crystals, brass- to bronze-yellow in color, are typically needle- or hair-like. They occur in radiating groups, or matted tufts, but fibrous coatings or crusts are common in some areas.

The mineral is scarce even though it has been reported from many localities. Milwaukee probably is the latest source of any appreciable amount of millerite.

History of Locality

Specimens of millerite from Milwaukee are included in scattered collections throughout the world. They are labelled as coming from Berthelet, North Milwaukee, Cementville, or Lindwurm (Lindwerm). Some are also labelled as coming from the Milwaukee Cement Quarry, Milwaukee River, Lincoln Park, Capitol Drive, Washington Street Bridge, or Humboldt Street Bridge in Milwaukee County. These names all refer to the same locality, which is now Estabrook Park, Milwaukee, Wisconsin.

The Milwaukee occurrence, though known for many years, has never been described in the literature. Hobbs (1), in a paper written in 1895, stated that specimens of millerite from the Milwaukee Cement Quarry were in the possession of a Mr. Howard Green of that city, but that he did not have an opportunity to study them. Cleland (2), in his paper on the Devonic of Wisconsin, mentioned millerite, but did not describe its occurrence, as his study was devoted primarily to the paleontology of that system. Dana (3) listed millerite from Milwaukee for the first time in the sixth edition of his *System of Mineralogy*, published in 1892. A short article by Wisniewski (4) reported another collection of millerite specimens that had been assembled by himself in recent years. The Thomas A. Greene library and collection, now in the Milwaukee-Downer College, contains records that millerite was known in 1884 when Thomas A. Greene exchanged millerite specimens with other collectors.

The millerite is found in the dolomitic limestone outcropping along the Milwaukee River in what is now Estabrook Park, in the northeastern part of the city. This park area was the scene of a cement-rock quarry during the early history of the city, but a flood caused abandonment of operations. Millerite was first obtained during this period during which quarrying took place.The river, after flooding the area, chose a new channel through the abandoned quarry, and the millerite-bearing rock was thus made inaccessible. This condition prevailed for about thirty years, or until 1936, when governmental projects were instrumental in again making this mineral available. The millerite-bearing rock was exposed as a result of widening and deepening of the river channel. The writer, who made frequent visits to the area, relocated the millerite-bearing "zones" and began collecting the mineral for study. Now (1940) the stratum which bears the mineral is again under water. Efforts to trace this particular stratum elsewhere along the river so far have failed. The millerite-bearing bed, which is gently undulating with the rest of the strata, appeared above the surface of the water only at a small falls at the northwest end of the old quarry.

Geologic Occurrence

The limestone that outcrops here belongs to the Milwaukee formation. It is Devonian in age, classified by some writers as Hamilton (5, 6). Millerite is found at two different stratigraphic horizons in this formation. The best specimens are found in a somewhat hard layer of massive-bedded, dull to bluish-gray dolomite, a part of a unit referred to by Cleland (2) as "Zone B," but which has been called by Raasch (7) the Berthelet member. The stratum containing the millerite is about two feet thick and is found in the upper part of this rock member. It is characterized by numerous small cavities which are lined with calcite cystals. Some of these cavities are formed by the dissolution of lumpy colonial bryozoa. The millerite, along with pyrite, marcasite, and sphalerite, is associated with the calcite. A similar cavernous stratum containing asphaltum lies just below this millerite-bearing bed, but it contains no millerite.

Another "zone" where millerite has been found, but in lesser amounts and usually somewhat weathered, lies in the Lindwurm member (7) which Cleland (2) called "Zone C." This stratigraphic unit overlies the Berthelet member (Zone B) and is made up of hard dull blue-gray shales interbedded with thin lenses of dolomite. The shales weather into a sticky gray mud, which contains numerous casts of fossil shells. Many of these casts are hollow and lined with calcite crystals; some of them contain millerite. Most common millerite-bearing fossils are *Atrypa reticularis* (Linnaeous), *Cyrtina hamiltonensis* (Hall), and *Cranaena iowensis* (Calvin).

Mineral Description

The writer has collected many beautiful well-crystallized specimens of millerite from this locality. They range in size from delicate hair-like forms to crystals as much as three inches long and 1/32 of an inch in thickness. Some radiating, almost solid masses also have been found. The crystals, however, are for the most part individually radiating from a common point embedded in calcite. The lustre is metallic, and the crystals are extremely flexible.

The green nickel carbonate, zaratite, occurs where oxidation of the millerite has taken place. Very few specimens of zaratite have been seen by the writer, however.

Calcite is the most abundant mineral in the cavities. It occurs as colorless translucent crystals which are generally less than one-half inch in length. Most of the crystals contain both positive and negative rhombohedrons, but some crystals of minute size that are commonly attached to the millerite hairs exhibit a simple rhombohedron.

Sphalerite is the most abundant of the sulfide minerals in the cavities. It is dark-brown to black in color and occurs in subhedral crystals which commonly are twinned. The twinned crystals are as much as one inch in diameter.

Pyrite and marcasite are less common; of the two, marcasite is the rarer. The pyrite crystals are brilliant in luster and commonly exhibit cubes and octahedrons. Marcasite occurs as bright iridescent, bladed crystals, or as globular or concretionary forms.

SEQUENCE OF CRYSTALLIZATION

In the specimens studied, millerite was the first of the cavity minerals to form. Crystals of this mineral extend through those of all the other minerals lining the cavities. Sphalerite was second, followed by pyrite and marcasite. Crystals of pyrite in some specimens have grown partly around the crystals of sphalerite. Calcite was the last to crystallize. Crystals of calcite surround the marcasite and pyrite crystals as well as millerite and sphalerite.

Origin. The origin of the millerite is not easily explained. Marcasite, pyrite, calcite, and sphalerite are found in sedimentary rocks in greater or lesser amounts in many localities, owing to precipitation from circulating ground waters. Millerite, however is not common in sedimentary rocks.

The particular difficulty in determining the origin of the millerite lies in finding the source of the nickel. Howarth (8), in discussing the origin of millerite in the South Wales coal field, concludes that the nickel there was derived by circulating ground water from basic igneous rocks that outcrop in the Cornwall district southwest of the coal field. A similar source for the nickel of the millerite at Milwaukee, however, is very improbable. The nearest outcrop of igneous rocks is approximately 100 miles to the northwestward, and these are primarily acidic rocks. There are no known buried igneous intrusives in the vicinity of Milwaukee. Furthermore, if such a rock had been the source, there is no reason to believe that millerite should not have been deposited in the underlying Silurian, Ordovician, and Cambrian rocks as well.

The possibility that the nickel may have been derived from seaweeds and other marine plants that lived in the Devonian seas is plausible. Both Clarke (9) and Lindgren (10) mention the occurrence of nickel in the ash of seaweeds and marine plants. Furthermore, fossil remains of marine plants are abundant in the Devonian rocks of this area. The very local occurrence of the millerite as compared with the wide occurrence of marine plant fossils discredits this hypothesis. Millerite is not associated with fossils of marine plants elsewhere. In addition, analyses of the dolomite do not show the presence of nickel.

Although no millerite occurs in the stratum containing the asphaltum, there may be a genetic relationship between the asphaltum deposit and the millerite in the overlying beds. Ellis (11) and Thomas (12) mention that nickel occurs in petroleum ash. The writer suggests that the nickel was derived from the asphaltum by circulating ground water and deposited as millerite in the more porous strata above.

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BOOK REVIEW

ELEMENTARY CRYSTALLOGRAPHY. John W. Evans and George M. Davies. vii+149 pages, 203 figures. Thomas Murby & Co., *London;* Nordeman Publishing Co., Inc., 215 Fourth Ave., *New York*, 1940. Cloth binding. Price $2.00.

The first edition of this non-mathematical morphological text on elementary crystallography appeared in 1924. Due to the death of the senior author in 1930, the second edition has been prepared by the junior author.

The material is based on instruction given for a number of years at Birkbeck College to students preparing for the Intermediate Examination of the University of London. At the end of each chapter "practical exercises" are indicated to test the student's mastery of the points stressed in the portion covered.

The second edition is virtually a reprint of the earlier edition with the addition of one new chapter of 15 pages dealing with atomic structure as revealed by recent *x*-ray studies.

W.F.H.

PROCEEDINGS OF SOCIETIES

PHILADELPHIA MINERALOGICAL SOCIETY

Academy of Natural Sciences of Philadelphia, May 2, 1940.

A stated meeting was held on May 2 with Dr. Thomas presiding. Sixty-four members and visitors were present. Mr. Thomas A. Wright spoke on the "Application of Spectrography to Mineral Analysis."

June 6, 1940

Dr. Thomas presided at the June meeting with 57 members and visitors present. Mr. Morgan exhibited datolite from Prospect Park, and apophyllite from the Lincoln tunnel. Mr. Knabe described a trip with Messrs. Trudell and Gordon to the fire-clay mines of Clearfield County, exhibiting siderite geodes with quartz and sphalerite, and barite.

Mr. Trudell reported on the gift to the society by his brothers and sister—a collection of micro mounts, thin sections, and catalogues of specimens of the late Robert J. Hagey. The catalogues are unusual because of the 127 colored crayon drawings, each four inches in diameter, of rock sections in polarized light.

Mr. Richmond E. Myers addressed the society on "Mineral Collecting South of the Border" which was illustrated with colored moving pictures taken in Mexico and Guatemala.

Harold W. Arndt, *Acting Secretary*

Ernest E. Fairbanks, New York City, has been appointed Associate Mineralogist with the U. S. Bureau of Mines, Eastern Experiment Station, College Park, Md.

ERRATA

Hess, H. H., and Phillips, A. H., *Am. Mineral.*, **25**, 276 (1940).

Table 2.

Recalculated analysis No. 3: Al_2O_3 should be 1.67. Recalculated analysis No. 8: should be SiO_2 53.88, Al_2O_3 2.16, Fe_2O_3 .85, FeO 12.40, MgO 27.58, CaO 2 19, Na_2O .07, K_2O .03, H_2O .34, TiO_2 .29, P_2O_5 .00, Cr_2O_3 .00, MnO .21.